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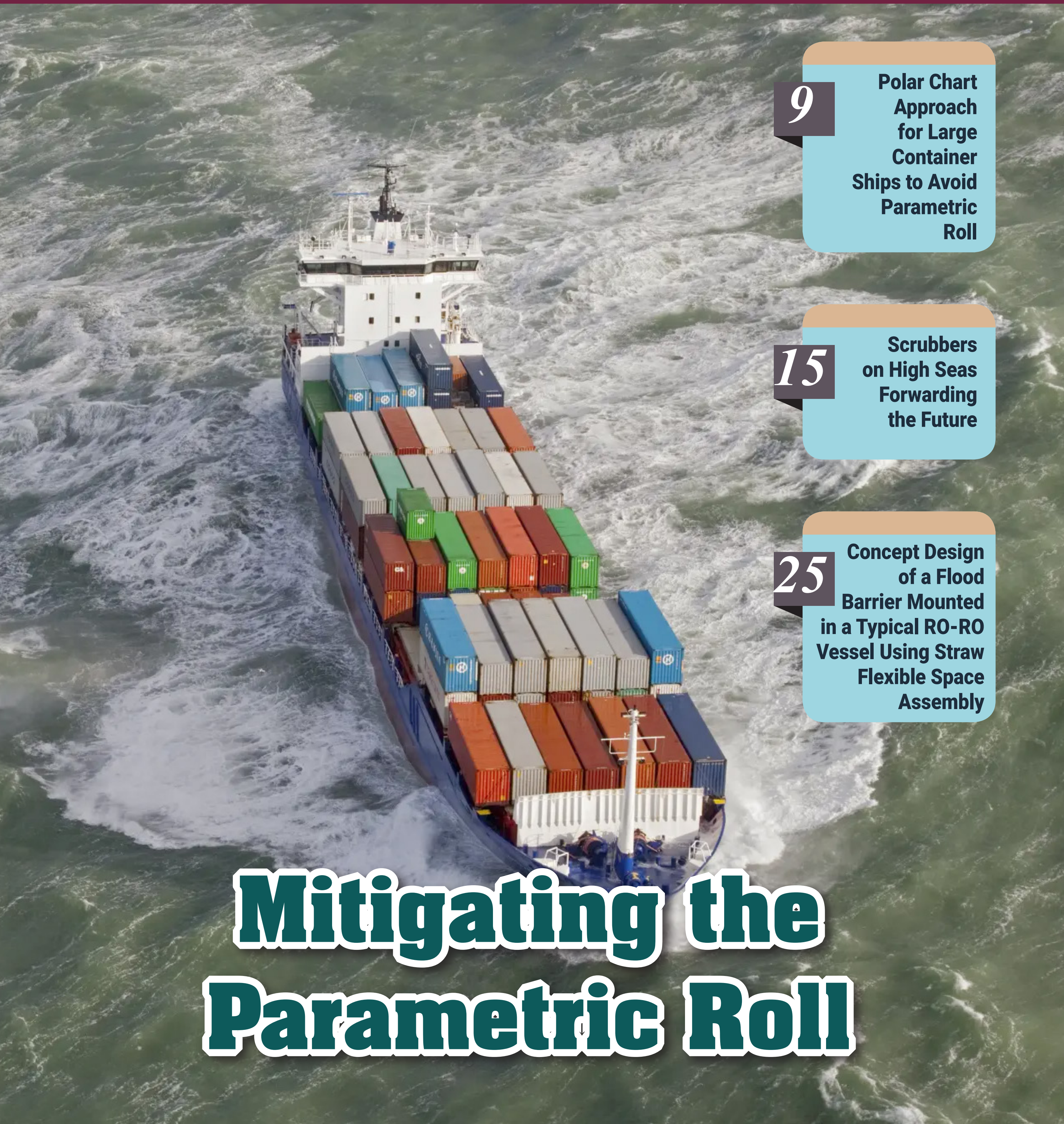

Mitigating the Parametric Roll

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EDITORIAL

Mixing one's wines may be a mistake, but old and new wisdom mix admirably.

- Bertolt Brecht

A series of maritime news has caused flutter and excitement. A select few are worth mulling upon. The first one surely in the liking is the news on MOL investing in India (real estate, ship registrations etc.). An exciting initiative is the company's enthusiasm to fund start-ups, especially for providing solutions for shipping and logistics. This is reassuring.

The next one is the tabling of the new Bill of Lading 2025 in the Parliament, ringing out the 160+ years old Bills of Lading Act. This would have to align with modernising (read: digitising) the ways of doing shipping business and documentation. This is a new step.

Then comes the DGS' cracking the whip on the fraudulent certificates drawing strength from he obligations under the Merchant Shipping (Recruitment and Placement of Seafarers) Rules. This is scratching a new itch caused by an old, persistent allergy.

Industry is also abuzz with another old directive of DGS on phasing out old ships. A mixture of old and new ships will prevail, we hope. There is more to come and one would be the rechristening of Director General of Shipping to Director General of Maritime Administration.

Good wisdom should reign allowing prudent, new order to come in. In that, a point to guide: Yes, new brooms sweep clean, but old brooms knows the corners.

In this issue

The first article is an interesting one on parametric roll on container ship. The Authors from Class NK propose a method: Generating a Polar Chart showing the results of roll angles and wave direction etc., which will help the operator to avoid the situation. The generation of the inputs will be based on the Grim's Theory (Grim's Theory: Given a particular moment, an irregular sea surface can be depicted by a regular wave whose length is equal to the vessel's length, with crest/trough at midships). This will be of interest to researchers and those seeking knowledge on parametric roll problems.

We follow with a paper from WMTC 24 on scrubbers. Manogaran Vijayakumar and Dr. Vimala present a case for scrubbers. After providing some known options for decarbonisation, the Authors go descriptive on the merits of scrubbers. Different fuels in-use are listed and nominal tabulations are presented, bereft of any economic figures. The paper mentions that the study has highlighted all the comparisons etc. The information provided is more on alternate fuels (well known by now) than the scrubbers. It is an easy read.

The next article presents an innovative idea for creating barriers on board ships to mitigate stability issues. A straw stuffed frame will serve as the 'flood barrier' and will be placed on the weather-exposed deck. The wall of straw will absorb the kinetic energy of the water hitting the frame, will retain and release the water soon after. A few strength calculations assure that the structure will be viable for the purpose. The Authors propose that this could be an option for Ro-Ro vessels. This is an easily digestible read.

The Technical Section has the concluding part on the Seafarers' stress and how occupational therapists can help. The Students' Section has a write-up on the possibility of autonomous firefighting, while discussing two big fire incidents.

The MER Archives of August 1985 has a Transaction on Marine Casualties. This is a technical treat for all practicing and other marine engineers.

Wishing away the tariff traumas (old and new), here is the August 2025 issue for your reading pleasure.

Dr Rajoo Balaji
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Polar Chart Approach for Large Container Ships to Avoid Parametric Roll

K. Takeda, F. Yanagimoto, K. Ishibashi

Abstract: An operational guidance in the form of polar chart showing the critical area of parametric roll is an effective means to provide a master with reference information on the risk of heavy roll motion. The authors applied a method based on the extended Grim's effective wave theory which is simplified and practical approach. This method can replace the stochastic assessment in irregular waves with the deterministic assessment in a regular wave, and its computational time is very low. In this study, some seakeeping test data with large container ships were used to validate polar charts. These experimental data include quartering wave data in irregular waves, which were rarely measured before. As another approach, the authors also investigated some reports on container loss accidents in recent years and compared the situation of accidents with the polar chart. As a result, it was found that the polar chart based on the extended Grim's effective wave theory can generally predict the occurrence of parametric roll in terms of seakeeping tank tests and actual accidents.

Keywords: Roll motion; Extended Grim's effective wave theory; Operational guidance.

Introduction

Parametric roll resonance was brought to much attention by the accident of C11 post-Panamax container ship in 1998. For recent large container ships, container loss accidents due to heavy roll motion, in which parametric roll has been identified or suspected to have occurred [1]. The number of container loss accidents is very rare, but it could have a significant impact on maritime transportation and industry. Unlike synchronous roll resonance oscillated by wave exciting forces, parametric roll gradually grows by the time-varying change in stability in waves and it might occur unexpectedly. As well known, when the natural roll period is twice the wave encounter period, parametric roll is likely to occur. Some reports on recent accidents of large container ships suggested that the condition of long natural roll period due to low GM and swell with approximately 5 to 6m of wave height from stern quartering are close to that of the occurrence of parametric roll [2-4]. When a ship is in such a condition, parametric roll may occur suddenly. According to the interview with the crews [2], the ship rolled intermittently before they noticed the container loss and damage. Even if its mechanism is known, it would be difficult to apply it to an actual operation and prevent parametric roll.

> *As well known, when the natural roll period is twice the wave encounter period, parametric roll is likely to occur*

Thus, a polar chart displaying visually roll angle can provide useful information to avoid the possible condition of parametric roll. IMO released the Interim Guidelines on the Second-Generation Intact Stability Criteria, MSC.1/Circ.1627 (SGISC) in which the requirements for operational guidance in the form of a polar chart are described in several ways [5]. When it comes to related studies for a polar chart, several examples based on various simulation code have been shown such as [6-8]. In TopTier JIP project for cargo securing safety on large container ship, a comparative study for polar plot of parametric roll were carried out with various 6-DOF (degrees of freedom) motion simulation [9].

Generally, more than 3-DOF motion simulation in a statistically enough irregular waves can be required to assess parametric roll, but there are several conditions such as ship speed, heading, wave period, significant wave height and GM and the computational cost is enormous.

Therefore, the authors applied a procedure based on the extended Grim's effective wave theory to realise very low simulation time. It is a simplified and practical approach since the stochastic assessment in irregular waves can be replaced by the deterministic assessment in the longitudinal regular wave [10, 11]. For validation of the polar chart, several model test data with container ships were used in this study [9, 11]. These experimental data include quartering wave data in irregular waves, which are very useful for the validation of the polar chart in all directions. As another approach, the authors also investigated the effectiveness of the polar chart by comparing with some reports for accidents in recent years [2, 3]. Accordingly, it was found that the polar chart based on the extended Grim's effective wave theory can generally cover the occurrence of parametric roll.

Polar chart approach

A polar chart for parametric roll usually shows the radial direction as the ship speed and the circumferential direction as the wave encounter angle. For an operation onboard, there is another method for displaying in which the angle is the azimuth (0 degree is North) so that the operator can visually recognise the ship's course and wave direction easily. The roll angle can be displayed directly, but it can also be linked to probabilistic risk, or some criteria related to safer operation.

This paper focuses on polar chart approach for avoiding parametric roll, but there are various ways to prepare it. Although more than 3-DOF (degrees of freedom) simulation can be performed, it is not easy to obtain the polar chart data for various sea conditions. Especially, a container ship is expected to require the large number of loading conditions. In this paper, a simple method based on the extended Grim's effective wave theory is adopted for preparing polar charts with reference to [10, 11]. If parametric roll simulation is performed in advance, polar chart data can be used onboard. For example, a polar chart can be easily displayed by inputting sea conditions and ship information such as draft and GM on a simple viewer as shown in **Figure. 1.**

"If parametric roll simulation is performed in advance, polar chart data can be used onboard"

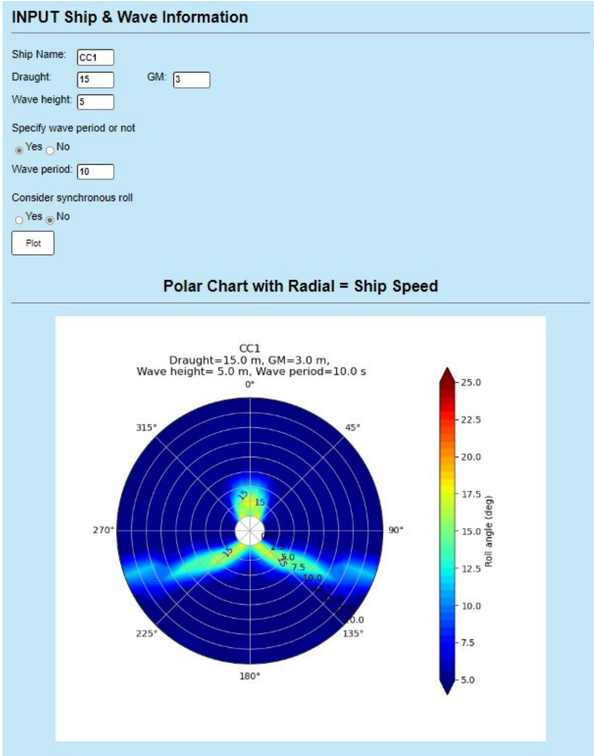

Figure. 1 An example of polar chart viewer

Comparison to seakeeping tank tests

A. 14K TEU class container ship

Figure. 2 shows the comparative results of a polar chart and representative experimental data introduced in [11]. This seakeeping tank tests used 14K TEU class container ship model with $L_{pp} = 352m$. GM and natural roll period were respectively adjusted 2.0m and 28.8s in full-scale. As for irregular wave conditions, wave spectrum is JONSWAP with long-crested wave and 1.5 of peak enhancement factor γ. Significant wave height is 6.4m and the peak wave period is 14.3s in this condition. The maximum roll angle in 30 degrees of wave encounter angle and 5knots of ship speed is approximately 12.7 degrees and it is plotted with same contour collar as the polar chart. The duration time in this condition was approximately 0.75 hours and the number of encounter waves was approximately 200. The value of the polar chart based on long-crested wave in the same condition is

19.7 degrees, which is larger than the experiment. According to [11], the polar charts generally tend to show conservative results rather than experimental data. Since parametric roll can be regarded as non-ergodic, measured data can be significantly different with different random phase.

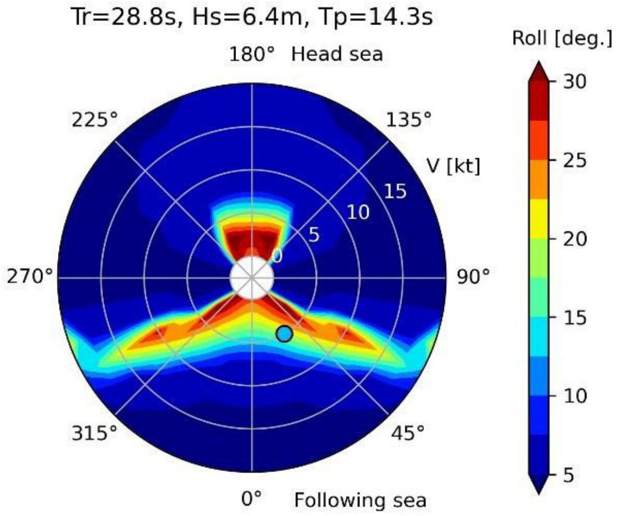

Figure. 2 Polar chart based on long-crested wave plotting maximum roll amplitude by the experiment with 14K TEU container ship [11].

B. 15K TEU class container ships

In TopTier JIP project, seakeeping model test were addressed with 10K TEU and 15K TEU container ship model [9]. In this paper, the comparative results of a polar chart and experimental data for 15K TEU container ship model with L_{pp} = 352*m* is shown in **Figure. 3.**

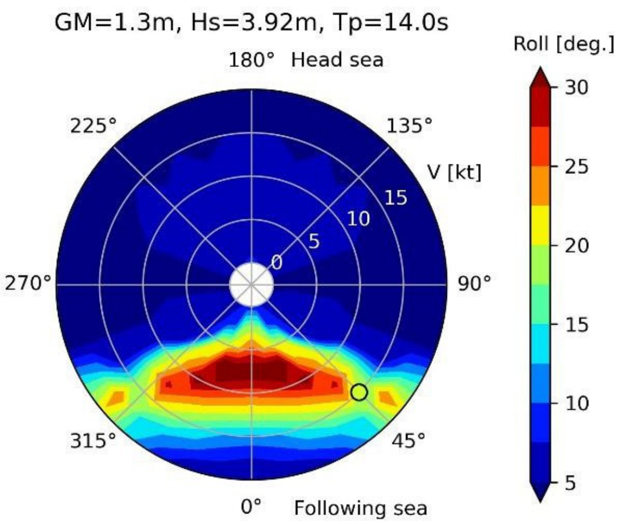

Figure. 3 Polar chart based on long-crested wave plotting maximum roll amplitude by the experiment with 15K TEU container ship [9].

GM and natural roll period were respectively 1.3m and 38.6s in full-scale. Irregular waves with 3-hour duration were generated using JONSWAP (γ = 3.3) with long-crested wave. Significant wave height is 3.92m and the peak wave period is 14.0s in this condition. The maximum roll angle in 45 degrees of wave encounter angle and 15knots of ship speed is approximately 20 degrees and it is plotted with same contour collar as the polar chart. While the value of the polar chart based on long-crested wave in the same condition is 19.7 degrees. Both results are almost same in this case.

> *However, since an excessive roll can trigger an accident directly, it is important to recognise in advance what conditions can cause parametric roll*

Although it may be difficult to estimate accurate roll angles under any conditions, the risk area of parametric roll can be covered by adopting the polar chart based on the extended Grim's effective wave theory.

Comparison to actual accident cases

The authors investigated the validity of the polar chart referring the information of some accident reports, case A [2] and B [3]. The conditions in the reports as shown in **Tables 1** and **2** are used for this comparative study, however there are some assumptions. First, since hull form data is not available, the authors used 14K TEU class container ship [11], whose size is like accident ships.

Regarding sea conditions at the time of the accident, these reports include several estimated wave height and wave period. The wave period and wave height of swell described in the report were regarded as the same as the peak wave period and significant wave height in the polar chart. Basically, it is difficult to specify accurate sea states and it should be noted that there are uncertainties. Finally, the polar charts were prepared using estimated natural roll period in the reports.

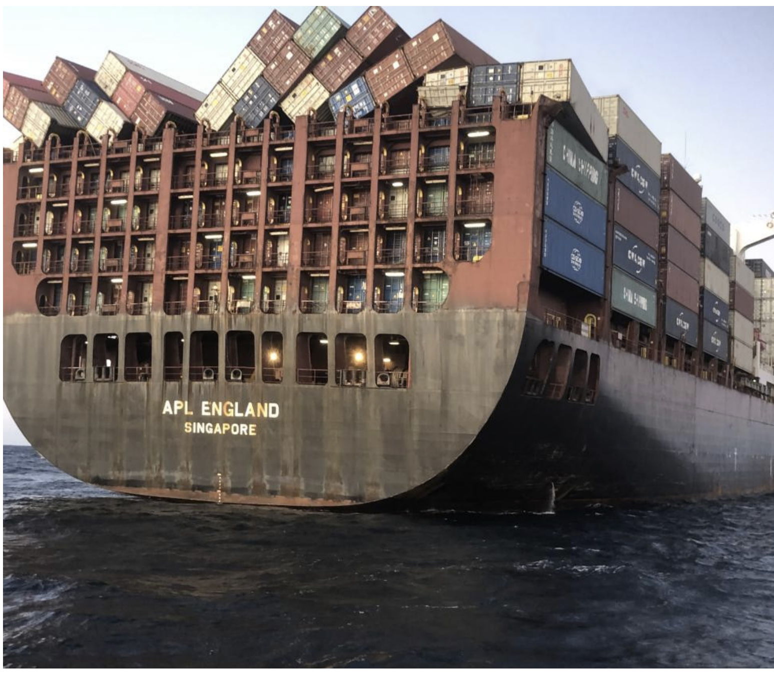

Table 1 Conditions of swell [2, 3]

Case	Wave height [m]	Wave period [s]	Wave direction [deg.]
A	6.0	15	300
B	4.8	16.8	310

Table 2 Conditions of the ship [2, 3]

Case	Natural roll period [s]	Ship speed [knot]	Ship course [deg.]
A	42.8	10	89
B	39.97	22	82

The polar chart here represents the radial direction as the ship speed and the circumferential direction as the azimuth to identify the state of ship speed and course. The observed maximum roll angles are approximately 26 degrees and 20 degrees respectively and it is plotted on each polar chart in **Figures. 4** and **5.** As shown in **Figures. 4** and **5,** the condition of the ship is respectively included in the zone where parametric roll can occur. **Table 3** shows the observed maximum roll angle and the value of the polar chart.

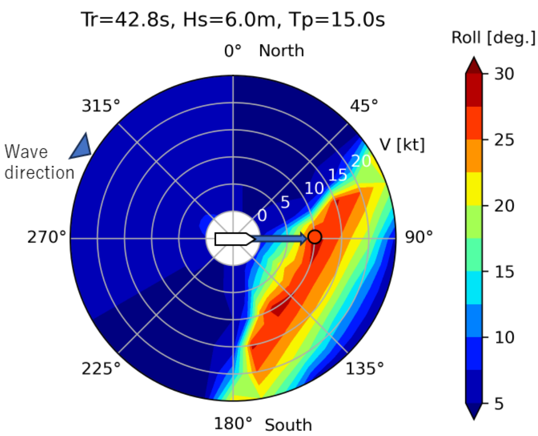

Figure.4 Polar chart based on long-crested wave plotting observed maximum roll amplitude by the report [2].

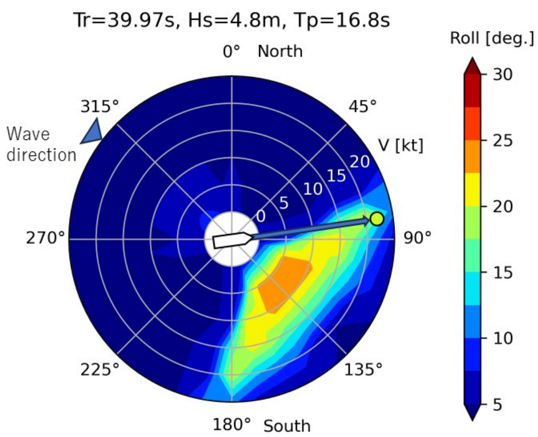

Figure. 5 Polar chart based on long-crested wave plotting observed maximum roll amplitude by the report [3].

Table 3 Comparison of roll angle [2, 3]

Case	Observed maximum roll angle [deg.]	Roll angle of polar chart [deg.]
A	26	29
B	20	16

Even if the ship is in the risk area in actual operation, heavy roll motion does not immediately occur. A serious accident involving container cargo loss would happen due to not only parametric roll but also multiple factors. However, since an excessive roll can trigger an accident directly, it is important to recognise in advance what conditions can cause parametric roll.

The relationship between the wave encounter period and natural roll period is critical for the occurrence of parametric roll, but wave encounter angle, wavelength, and significant wave height are also important factors. Even if its mechanism is known, it would be difficult to apply it to an actual operation. Thus, the polar showing visually roll angle can provide useful information to avoid the possible condition of parametric roll.

Conclusions

The authors proposed the polar chart using a method based on the extended Grim's effective wave theory and found that it could reproduce the occurrence of parametric roll by comparing several experiments and actual accident cases. Many studies have focused on the parametric roll in a longitudinal wave however it occurred in quartering waves for recent large container ships. The polar chart adopted in this study can cover the range of the parametric roll even in quartering waves. Although parametric roll does not occur immediately in the risk area of the polar chart, it is useful to recognise the possibility of its occurrence in advance. Furthermore, from a practical point of view, it is useful to combine the polar chart with the weather routing to avoid the sea state where parametric roll occurs beforehand. Additionally, a polar chart system will contribute to safer operation if the risk of parametric roll can be recognised by linking with navigation equipment or weather forecasts.

ACKNOWLEDGEMENT

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[This Paper was presented in the WMTC 2024; 4-6 Dec 2024, Chennai]

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Scrubbers on High Seas Forwarding the Future

Manogaran Vijayakumar,
RTV Vimala

Abstract: This report discusses a four-year study on the effect of Exhaust Gas Cleaning System (Scrubbers) over the 0.5% VLSFO and other alternative fuels. The study involves commercially attractive, economically viable among available mature technologies for transition towards IMO's net zero emission by the year 2050. Likewise assessed the actual behaviour of the ship in real life and take out of the best among the existing fleet and existing technology. Aligning the market dynamics, improving, and optimising performance of the fleet and distributing cost along the divided chain of ship owners, charterers, cargo owners. Exhaust Gas Cleaning System (Scrubbers) gives a significant impact and front runner in progress towards achieving the regulatory landscape tightening rules among 0.5% VLSFO and alternative fuels such as Hydrogen, Ammonia, Methanol, LPG, LNG, Battery etc.

Key Words: EGCS (Scrubbers); Hydrogen; Ammonia; Methanol; LNG; LPG etc.

1. Introduction

The maritime industry stands at a critical crossroads as it seeks to achieve the International Maritime Organization's (IMO) ambitious goal of net-zero emissions by 2050 [10]. Central to this endeavour is the adoption of Exhaust Gas Cleaning Systems (Scrubbers) and a transition to alternative fuels. The study in focus here meticulously examines the cost effectiveness of scrubbers when used with 3.5% High Sulphur Fuel Oil (HSFO) and other alternative fuels. This report, with its broad scope, detailed methodology, and significant findings, offers an in-depth understanding of the commercial, economic, and regulatory implications of these technologies.

Scrubbers are identified as a commercially attractive solution. They enable continued use of higher sulphur fuel oil while ensuring compliance with sulphur emission regulations, making them economically viable in the short to medium term, especially given the fluctuating costs of compliant fuels.

Performance Optimisation

Ships equipped with scrubbers demonstrated significant improvements in operational efficiency and compliance with emission standards. The study highlighted the importance of optimising scrubber performance through regular maintenance and technological upgrades.

> ***The study revealed that scrubbers, when properly maintained and optimised, significantly improve a ship's operational performance***

Impact on Regulatory Compliance

Scrubbers play a crucial role in meeting IMO's sulphur emission regulations. The study found that scrubbers effectively reduce sulphur emissions to the required levels, positioning them as a key technology for achieving regulatory compliance.

Alternative Fuels

The study explored the potential of alternative fuels in reducing Green House Gas emissions. While hydrogen, ammonia, methanol, LPG, LNG, and battery technologies show promise, each comes with its own set of challenges, including infrastructure requirements, safety concerns, and economic feasibility [9].

Cost Distribution

The analysis of cost distribution among stakeholders revealed that while the initial investment in scrubbers and alternative fuels can be high, the long-term savings from fuel cost reductions and regulatory compliance can be substantial. The study emphasised the need for collaborative investment strategies to distribute costs effectively.

The study will elaborate the detailed analysis of Operational Performance, Alternative Fuels, Impact on Regulatory Compliance, and Cost Distribution.

2. Operational Performance

The study revealed that scrubbers, when properly maintained and optimised, significantly improve a ship's operational performance. Regular maintenance and technological upgrades are essential to ensure scrubbers operate at peak efficiency. Ships equipped with scrubbers consistently met the sulphur emission standards set by the IMO, demonstrating their effectiveness as a compliance tool [1,12].

3. Challenges with Alternative Fuels

i) Hydrogen and Ammonia

Hydrogen and ammonia are promising fuels for achieving GHG emission reductions. Both have high energy potential and produce zero carbon emissions when used [3]. However, their widespread adoption faces significant hurdles:

Storage and Handling: Both hydrogen and ammonia require specialised storage and handling infrastructure due to their chemical properties. Hydrogen, being the lightest element, needs to be stored under high pressure or at extremely low temperatures, which demands significant investments in storage facilities and safety measures. Ammonia, while easier to store than hydrogen, is toxic and poses handling risks.

Infrastructure Development: The existing maritime infrastructure is not equipped to handle hydrogen or ammonia at a large scale. Developing the necessary infrastructure would require substantial investment and time, posing a barrier to immediate adoption.

ii) Methanol

Methanol is relatively easier to handle compared to hydrogen and ammonia and can be produced from renewable sources, making it an attractive option. However, it still requires significant technological advancements for widespread adoption.

Production and Availability: While methanol can be produced from natural gas, coal, and biomass, the availability of renewable methanol is currently limited. Scaling up production to meet maritime demands would require considerable effort and investment.

Energy Density: Methanol has a lower energy density compared to traditional marine fuels, meaning larger fuel tanks or more frequent refuelling would be necessary, which could impact the design and operation of ships.

iii) LPG and LNG

LPG and LNG are more mature technologies with existing infrastructure. They offer lower GHG emissions compared to traditional marine fuels, but still produce carbon emissions:

Infrastructure and Maturity: Both LPG and LNG have well-established supply chains and infrastructure, making them easier to adopt in the short term. Many ports already have the necessary refuelling facilities.

> ***"Methanol and Ammonia: These fuels have the potential to become more price competitive with technological advancements and economies of scale"***

Emission Reduction: While LPG and LNG produce lower carbon emissions than conventional fuels, they are not entirely carbon-free. LNG still emits methane, a potent greenhouse gas, during production and transport.

iv) Battery Technologies

Batteries are ideal for short-sea shipping and ferries, offering zero emissions at the point of use [5]. However, their application in deep-sea shipping is limited by current energy density and recharging infrastructure:

Energy Density: Current battery technology does not provide the energy density required for long voyages. Batteries are more suitable for short-sea shipping routes where recharging can be done frequently.

Recharging Infrastructure: The infrastructure for recharging large maritime batteries is still in its infancy. Significant investments in port facilities and grid capacity would be necessary to support widespread adoption.

Apart from this, the transition to alternative fuels presents several practical challenges:

Safety Concerns: Handling and storing alternative fuels such as hydrogen and ammonia pose significant safety risks. Developing robust safety protocols and training personnel is crucial to mitigate these risks.

Crew Training: Transitioning to new fuels and technologies requires extensive training for ship crews. Understanding the properties, handling, and operational procedures for new fuels is essential for safe and efficient operations.

Retrofit and New Build Costs: Converting existing ships to use alternative fuels or building new ships designed for these fuels involves significant costs. The study emphasised the importance of financial support and incentives to facilitate this transition.

4. Economic Analysis of scrubbers

The economic analysis conducted in the study provides a clear picture of the financial implications of adopting scrubbers and alternative fuels [2,6]. The price spread between different marine fuels is a complex interplay of several factors, including:

Crude oil prices: The underlying cost of crude oil significantly impacts the price of all petroleum-based fuels.

Refining margins: The profitability of refining processes influences the price differentials between various fuel grades.

Sulphur content: Fuels with lower sulphur content generally command higher prices due to additional refining processes required.

Environmental regulations: Stricter emissions standards can increase the price of fuels that comply with those regulations.

Market demand: The supply and demand dynamics for each fuel type influence their respective prices.

Geographical location: Fuel prices can vary significantly depending on the region due to factors such as transportation costs, taxes, and local market conditions.

Initial Investment and Operational Costs

The initial investment in scrubbers can be substantial, including the cost of installation and integration with existing ship systems. However, the study found that the operational cost savings from using other alternative fuel oil can offset this investment over time. Additionally, scrubbers enable compliance with sulphur regulations without the need for more expensive low-sulphur fuels.

Long-Term Savings and Compliance Costs

The study highlighted the long-term financial benefits of adopting scrubbers and alternative fuels:

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Fuel Cost Savings: Using scrubbers allows ships to continue using less expensive high-sulphur fuel oil, resulting in long-term fuel cost savings.

Similarly, alternative fuels such as LNG and LPG can offer cost savings compared to traditional marine fuels, depending on market prices.

5. Price Spread: A Comparative Overview

Conventional Marine Fuels

HSFO (High Sulphur Fuel Oil): Historically the cheapest option, its price has been impacted by the IMO 2020 regulations, which mandated a global sulphur cap for marine fuels.

VLSFO (Very Low Sulphur Fuel Oil): Introduced to comply with IMO 2020, VLSFO is generally more expensive than HSFO due to the additional refining processes required to reduce sulphur content.

The price difference between HSFO and VLSFO is often referred to as the Hi-5 spread. This spread has fluctuated significantly over the years, influenced by factors such as crude oil prices, refining margins, and market demand.

Alternative Fuels

The price spread between conventional marine fuels and alternative fuels is even more pronounced due to the nascent stage of the latter.

LNG (Liquified Natural Gas): While offering lower emissions, LNG prices are influenced by natural gas prices, liquefaction costs, and transportation infrastructure.

LPG (Liquified Petroleum Gas): Similar to LNG, LPG prices are tied to crude oil prices and the availability of LPG feedstock.

Methanol: Methanol prices are influenced by natural gas and coal prices, as well as production costs.

Ammonia: As a relatively new marine fuel, ammonia prices are still developing and influenced by production costs and transportation logistics.

Hydrogen: Currently, the most expensive option, hydrogen prices are dependent on production methods (green, blue, grey) and distribution infrastructure.

Battery technology: While not a fuel, the cost of batteries for electric or hybrid vessels is a significant factor in overall operating expenses.

Price Spread Overview

The price spread between different marine fuels is influenced by a complex interplay of factors, including:

Crude oil prices: The foundation for most marine fuels.

Refining costs: The complexity of refining processes for different fuel types.

Environmental regulations: Stricter emissions standards often lead to higher prices for compliant fuels.

Market demand: Supply and demand dynamics for each fuel type.

Infrastructure costs: The cost of developing and maintaining infrastructure for fuel production, storage, and distribution.

Comparative Pricing

The following is a general comparison and actual prices can vary significantly based on location, time, and market conditions.

HSFO and VLSFO: The price difference between HSFO and VLSFO (Hi-5 spreads) has fluctuated significantly since IMO 2020.

LNG: While offering environmental benefits, LNG price competitiveness depends on natural gas prices, infrastructure development, and government policies.

Methanol and Ammonia: These fuels have the potential to become more price competitive with technological advancements and economies of scale.

Hydrogen: Significant cost reductions are needed for hydrogen to become a viable marine fuel.

Battery technology: Battery costs are decreasing, but their overall impact on vessel economics depends on factors like energy storage capacity and charging infrastructure.

Cost-Benefit Analysis Framework

A comprehensive cost-benefit analysis would involve the following steps:

Identify costs and benefits: Determine all relevant costs and benefits for each fuel option.

Quantify costs and benefits: Assign monetary values to as many costs and benefits as possible.

Discount future costs and benefits: Adjust future values to account for the time value of money.

Calculate net present value (NPV): Determine the overall profitability of each fuel option.

Sensitivity analysis: Assess how changes in key variables affect the results.

6. Environmental Impact

The environmental impact of scrubbers and] alternative fuels was a key focus of the study [7,8].

Scrubbers and Emission Reductions

Scrubbers effectively reduce sulphur oxide (SOx) emissions, helping ships comply with the IMO's 0.5% sulphur cap. The study also noted that scrubbers can reduce particulate matter emissions, contributing to overall air quality improvement. Closed-loop and hybrid scrubbers, which recirculate wash water, were identified as more environmentally friendly options.

Additional Considerations

Regional price differences: Fuel prices can vary significantly between different regions due to factors like taxes, transportation costs, and local market conditions.

Fuel blending: Blending different fuels can create new price points and potentially reduce emissions.

Carbon pricing: The implementation of carbon pricing mechanisms can impact the relative cost of different fuels.

7. Policy and Regulatory Implications

Regulatory framework: Analyse the role of regulations in driving the adoption of Scrubbers and alternative fuels.

Incentive programs: Discuss the effectiveness of government incentives in promoting cleaner technologies.

Research and development: Identify areas for further research to support the transition to low-carbon shipping.

Regulatory Compliance: Investing in scrubbers and alternative fuels ensures compliance with current and future IMO regulations, avoiding potential fines and operational restrictions. The study emphasised that early adoption of these technologies could provide a competitive advantage as regulatory requirements become more stringent [11,13].

Factors influencing fuel price

Fuel Type	Price Relativity	Factors Affecting Price
HSFO (High Sulphur Fuel Oil)	Lowest	Historically cheapest due to lower refining costs, but price has increased due to IMO 2020 regulations.
VLSFO (Very Low Sulphur Fuel Oil)	Higher than HSFO	More expensive due to additional refining processes to meet IMO 2020 sulphur cap.
LNG (Liquified Natural Gas)	Varies	Linked to natural gas prices, liquefaction costs, and transportation infrastructure. Can be competitive in some regions.
Methanol	Varies	Price influenced by natural gas or coal feedstock, production costs, and transportation.
Ammonia	Highest	Currently the most expensive option due to production challenges and limited infrastructure.
Hydrogen	Extremely high	Production costs, storage, and distribution challenges contribute to high prices.
LPG (Liquified Petroleum Gas)	Lower than LNG	Price linked to crude oil prices, but generally cheaper than LNG due to different production processes.
Battery	Not directly comparable	Cost of batteries is a component of overall vessel operation, not a fuel price.

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8. Conclusion:

The maritime industry's pursuit of the IMO's net-zero emissions by 2050 hinges on the adoption of Exhaust Gas Cleaning Systems (Scrubbers) and alternative fuels. This study highlights the commercial viability of scrubbers, which enable compliance with sulphur emission regulations while allowing the continued use of high sulphur fuel oil. Scrubbers have proven effective in improving operational efficiency and regulatory compliance, making them a key short to medium-term solution.

The economic analysis shows that while the initial investment in scrubbers are moderate, long-term savings from fuel cost reductions and regulatory compliance can be substantial. Environmental benefits are notable, with scrubbers effectively reducing sulphur oxide emissions.

Policy and regulatory support, including government incentives and carbon pricing, are crucial for driving the adoption of these technologies. Early adoption could provide a competitive edge as regulations become more stringent.

In conclusion, scrubbers are vital for the maritime industry to achieve sustainability goals, offering a balanced approach to operational efficiency, economic viability, and environmental responsibility.

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Concept Design of a Flood Barrier Mounted in a Typical RO-RO Vessel Using Straw Flexible Space Assembly

Krithik Eeswar S, A S Siddharth, Satheesh Babu

PK**Abstract**: Many severe ship accidents in the past were caused by a large water ingress followed by the progressive flooding affecting the watertight integrity of the ships and finally resulted in the sinking or total loss of the vessels. These accidents show an urgent need for a better solution to restrict the flooded area especially in RO-RO ships, where the open deck area is more. Divided into three parts, the straw-based flexible space assembly flood control system consists of columns, inclined rod supports situated behind the columns, and water baffles. Connecting rods are used to join the incoming and backing boards of the straw water baffles, which are separated by the straw that is packed in between them. By using straw to build a mountable flood wall, this study provides new ideas for useful applications of straw and for the development of assembly flood control facilities onboard ships. A numerical analysis model of the straw flexible space flood control system is established using ANSYS software. The study involves the possibility of activation of the flood barrier which is positioned in line with transverse bulkheads. Once a particular deck starts getting flooded due to a breach in the watertight integrity. The study's findings point to the installation of a flood control system made of straw flexible space assemblies as an economically viable option. This system can reduce the impact of flooding by converting the kinetic energy of waves from static to dynamic water in the flexible space, as well as into potential energy from the compression of straw. Therefore, it provides impact resistance, enhances the stability of the flood control system, and serves as a buffer. In this study, straw is an important material of the water barrier developed to facilitate the reuse of the flood control device. Furthermore, straw flexible space theory is applied to not only enable the proposed system to counter the impact of flooding of decks but also ensure the comprehensive use of straw.

Keywords—RO-RO Vessels, Flood Barrier, Straw-Flexible Space Assembly

Introduction

There are numerous risks that could jeopardize a ship's safety while at sea, including the crew on board. Ship flooding is one of these risks, which, in the worst situation, might quickly result in the loss of both human and vessel life. Water intrusion causes flooding, which ultimately compromises the ship's stability and watertight integrity. The consequences could be disastrous if water seeps into sections that are supposed to be dry, such the engine room and cargo holds. Ship flooding can be caused from:

a) Damage in vessel's hull due to collision with other vessel, contact or grounding

b) Heavy weather such as typhoons and hurricanes

c) Leakages at the ballast tanks

d) Leakages at the engine room from equipment related with sea water

e) Human error

A passenger ship that suffers from extensive flooding and then capsises is one of the calamity types when the crew has little time to react and could cause a significant number of fatalities. To this end appropriate risk models are needed, provided that they focus on the right parameters, and can deliver the right information at the right time. The likelihood of a ship flooding is a complicated subject that is known to be influenced by a variety of factors, one of which is the state of the watertight door (WTD).

In order to reduce the amount of flooding in the case of an accident, the watertight doors are frequently installed in the bulkheads that divide the ships into watertight (WT) compartments. This ensures that sufficient stability and reserve buoyancy are achieved. The watertight integrity of the ship is put at risk when these doors are left open longer than is necessary for crew members to pass through them safely.

Numerous studies have been done on flood walls by various researchers, including the lift type, the side-turning flapper type, the water-filled woven bags, the water-filled rubber bags, and mechanical testing as well as finite element simulations. In order to analyse the force forms and damage patterns of a lightweight movable floodwall, water retention experiments were performed on the floodwall utilising a water retention testing machine.

To create a plausible floodwall model, ANSYS numerical simulation was performed, and field floodwall tests were conducted using the simulation results. Researchers have carried out an experimental investigation of the mechanical attributes and leaking traits of portable flood management systems.

I. Design of flood control system

A. The Straw Flexible Space Assembly Flood Control System's composition

Divided into three parts, the straw flexible space assembly flood control system consists of inclined rod supports behind the columns, water baffles, and columns. The straw is stuffed between the oncoming and backing boards of the straw water baffles, which are separated into oncoming and backing boards and joined by connecting rods. There are two types of columns: side columns and central columns. The water baffles are fixed with the columns. In order to guarantee adequate anti-overturning performance of the straw flexible space assembly type flood control system, inclined rods are employed to offer support behind the columns. **Figure 1** depicts the straw flexible space assembly type flood control system created on AutoCAD.

B. Material Choices for the Straw Flexible Space Flood Management System

One of the primary materials of the flood control system are water baffles, and the panels made of these baffles are made of aluminium alloy. Water baffles have a longer service life because aluminium alloy resists corrosion well and does not rust quickly, even after extended contact with water. Columns need to have strong stability, a high resistance to overturning, and other qualities because they are one of the primary force members. They must also perform well during welding. Therefore, Q235 steel is used as the column material in order to facilitate column processing. Furthermore, it can guarantee that the general stability of the structure and the flood control system's ability to endure bigger waves. Straw exhibits good water absorption and expansion properties in addition to a robust deformation capacity. Straw is therefore utilised as a filler in flexible spaces. **Table 1** provides a summary of the mechanical property parameters of the materials that make up the straw flexible space assembly flood control system.

In order to reduce the amount of flooding in the case of an accident, the watertight doors are frequently installed in the bulkheads that divide the ships into watertight (WT) compartments

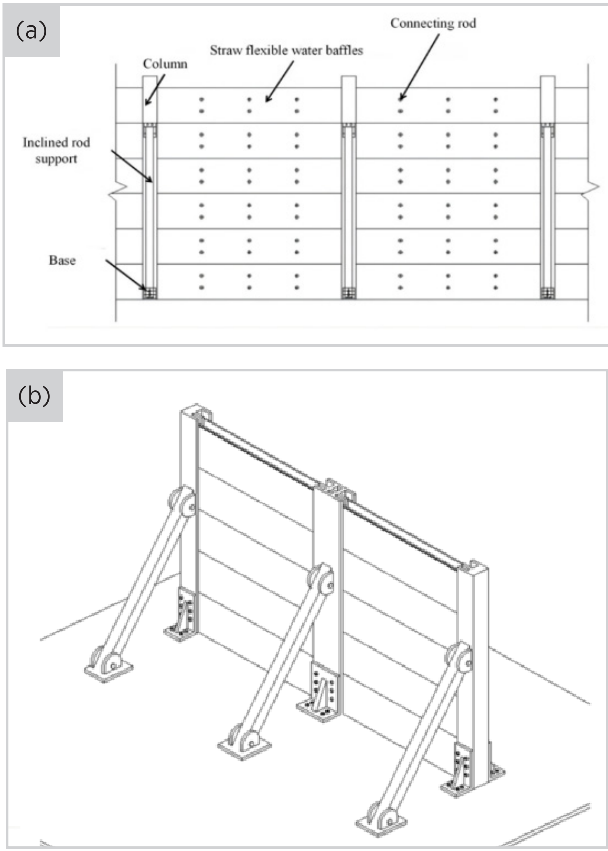

Figure 1: Flexible space flood control system in straw form.
(a) The flood control system's composition.
(b) Raising the flood control mechanism.

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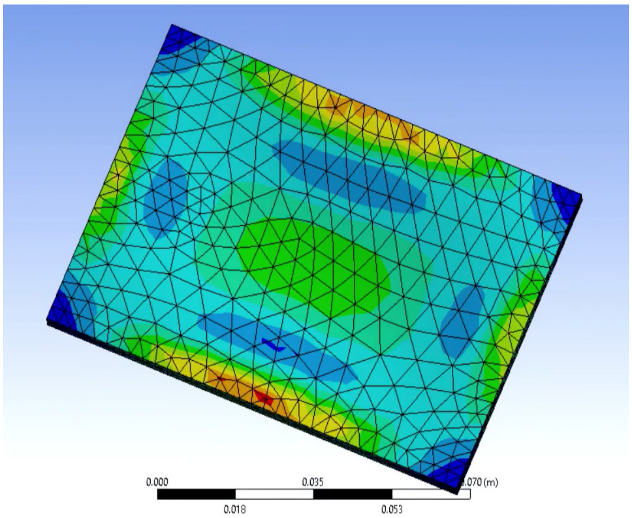
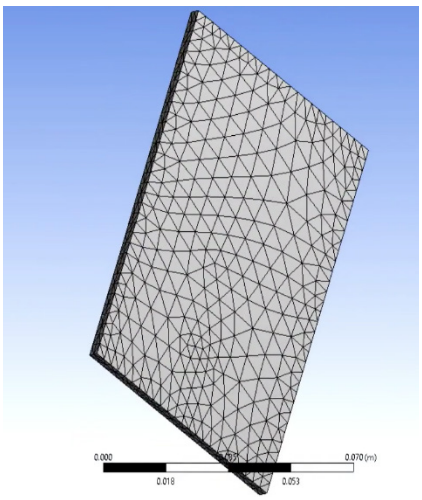
TABLE I. Mechanical property parameters of each component material.

	Mechanical property			
	Type	***Density(KN/m³)***	***Modulus of Elasticity (Pa)***	***Poisson's Ratio***
Water baffles	Aluminium alloy 6061	27	7×10^{10}	0.34
Column	Q235B	78.9	20.6×10^{10}	0.3
Inclined rod support	Q235B	78.9	20.6×10^{10}	0.3
Connecting rod	EN1.4301	78.9	20.6×10^{10}	0.3
Bolt plate	Q235B	78.9	20.6×10^{10}	0.3
Straw	-	4	1.9×10^{9}	0.3

II. Ansys analysis



(a)



(b)

Figure 1: Ansys analysis of the flood barrier plate. (a) The total equivalent stress experienced by the plate. (b) meshing of the plate for piecewise analysis.

At first we have determined the material to be used for the flood barrier. We chose a static structural analysis as our analysis parameter. After which , we drew the geometry of the floodwall according to the dimensions and used the extrude command in accordance with the thickness of the plate fixed.

Now, we do the modelling part and start with the meshing of the plate that can be seen in the **figure (a).** Now we introduce the central pressure that is assumed to be exerted due to the flooded water and then mention the parameters to be measured(total equivalent stress and strain, principal deformation etc.).Now ,we generate the solution and the program is run. We obtain the results on screen (as shown in **figure (b))** and we get to know the structural limits of the structure that meets our criteria required for our floodwall.

III. Development and Validation of the Straw Flexible Space Hypothesis

A. Theory of Straw Flexible Spaces

The flood control structure is flexible. The backing and approaching panels are connected in a flexible manner. Connecting rods hold the backing and incoming boards together, and they are made with movable parts. The straw-filled water baffles will compress the water board when it is subjected to wave load impact. The straw's elastic-plastic deformation acts as a buffer rather than having an immediate impact on the column or the water board. The distorted straw quickly reverts to its original shape after the impact force is removed. The water board maintains the starting position, allowing for the creation of space by the wave's impact and the straw's expansion following the water board's absorption of water. The combined force of the wave impact and the supporting force of the straw on the headboard forms what is known as the straw flexible space.

Thus, the straw flexible space hypothesis is put out, which states that because of the space between the water board and the two sides of the column, the static water in the

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straw flexible space turns into dynamic water during the operation of the flood control system. As a result, some of the wave impact kinetic energy is transformed into water kinetic energy and some of it is drained away by the straw deformation buffer in the flexible space. The backing board and column can bear the impact force because of the straw's flexible gap. It enhances the stability and impact resistance of the flood control system by lowering the impact force on the columns and backsplash.

B. Analysis of Forces on a Straw Flexible Baffle in the Presence of a Uniform Water Flow

The following formula is used to determine the floodwater's flow force on the water baffles when flooding occurs:

$$F_w = C_w \frac{\rho}{2} \upsilon^2 A$$

where ρ is the water density, υ is the design flow velocity, A is the baffle board's area, F_w is the water flow force, and C_w is the water flow resistance coefficient.

On the water baffle, the hydrostatic pressure is determined by

$$S_0 = P_c A$$

where h_c is the depth below the liquid surface at the centre of the water baffles shape, g is gravitational acceleration, and P_c is the pressure at the centre of the water baffles shape, which is equal to $\rho g h_c$.

$$F = \sigma A_1$$

where A_1 is the cross-sectional area of the straw between the backing and water-bearing plates, and σ is the compressive strength of the straw material.

Concept Design of a Flood Barrier Mounted in a Typical RO-RO Vessel Using Straw Flexible Space Assembly: (the straw on the baffle at a constant flow velocity, the water flow force, and the water pressure). These forces are related as

$$F = F_w + s_0$$

IV. IMPLEMENTATION OF THE FLOOD BARRIER ONBOARD RO-RO SHIPS

Ro-Ro vessels are built to accommodate wheeled cargo. Large open decks with robust ramps at the ship's front and rear are a feature of these vessels. These ramps are height-adjustable to suit a range of car and freight configurations. The open design allows vehicles to be driven directly onto the ship, making the loading process straighter forward. Inside the Ro-Ro vessel, the decks are organised to maximise cargo capacity and security of shipments. There could be several levels to the decks, and each car is carefully positioned and secured with lashings to provide stability. Crew members are responsible for strategically arranging the cargo to optimise space utilisation and maintain a balanced load distribution. As a result of which, the amount of open deck without transverse bulkhead is more compared to other vessels.

Even if a single deck gets flooded ,it would result in the flooding of almost one fourth of that deck .This would adversely affect the stability conditions of the ship and increasing the chance of an accident due to loss of transverse stability. When a particular part of the deck gets flooded ,it would act as a ballast tank and the ship would trim or roll accordingly. This situation brings out the need of additional watertight barriers in order to restrict the area of flooding to smaller regions and thus decreasing the chance of accidents.

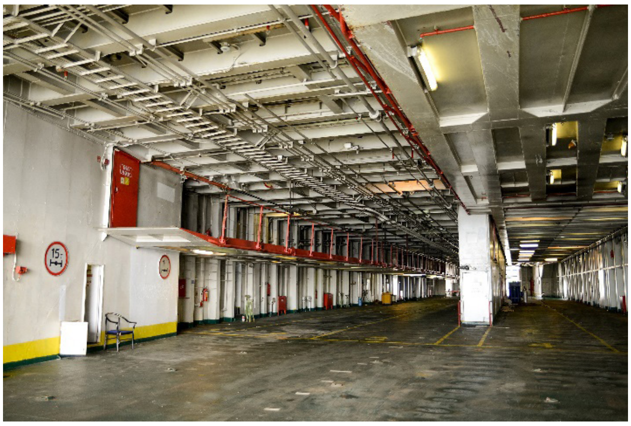


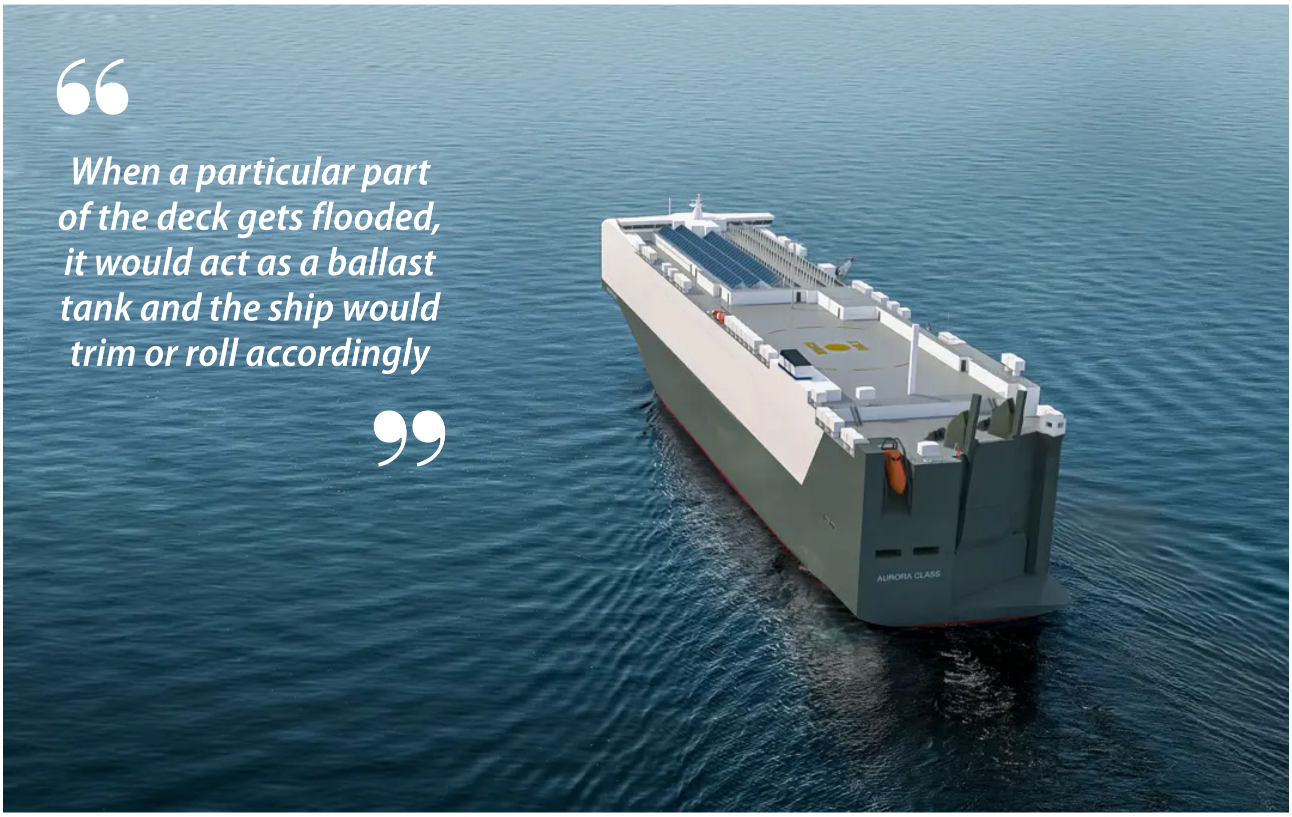
Figure 2: A typical deck in a Ro-Ro ship

> *The water board maintains the starting position, allowing for the creation of space by the wave's impact and the straw's expansion following the water board's absorption of water*

Whenever there is a breach in the watertight integrity due to adverse situations like collision, weather conditions etc., the deck may get flooded.

At such circumstances, the straw flexible space assembly will play a pivotal role in restricting the amount of flooding to the breached area The flood barrier arrangement is placed in line with transverse stiffeners and whenever flooding is detected in a particular deck, the flood barrier is launched and restricts the flow to a confined space. In such a manner, the stability of the ship is maintained. It is designed in such a way that it can withstand huge loads imparted due to the flooding and serves as an economically feasible option.

Once the flood barrier is fully launched ,it gets merged with the upper deck and the top surface of the



flood barrier is made in such a way that, the ends of the flood barrier fits right within its boundaries .It acts as a watertight wall and preventing the flooding of adjacent compartments.

V. Conclusion

A straw flexible space assembled flood control system was designed on the basis of Revit, and the straw flexible space theory was proposed. Thus, the feasibility of the straw flexible space assembled flood control system onboard Ro-Ro ships was verified. The main conclusions of this study can be summarised as follows:

1. The flood control system is mainly composed of a straw flexible water barrier, column, tilt rod support, and base. The straw flexible space can convert the wave impact kinetic energy from static water to dynamic water in the flexible space as well as into potential energy of straw compression, thereby draining away some of the flood's impact, in accordance with the elasticity of the straw material suggested by the straw flexible space theory. As so, it provides impact resistance, enhances the stability of the flood control system, and serves as a buffer;
2. The straw has a supporting effect on the baffle after water absorption and expansion, which makes the strain value of the baffle with straw under hydrostatic conditions greater than that without straw. Thus, straw as a filler in the flood control system can not only enhance the stability of the system but also satisfy the theoretical assumption of a flexible spatial flood control system with straw;
3. On the event of flooding ,the flood barriers act as the most effective and economically feasible option to restrict the flooding to a confined area and thus preserving the stability of the ship.

[This paper was presented at the CC Marpol Conference, February 2024]

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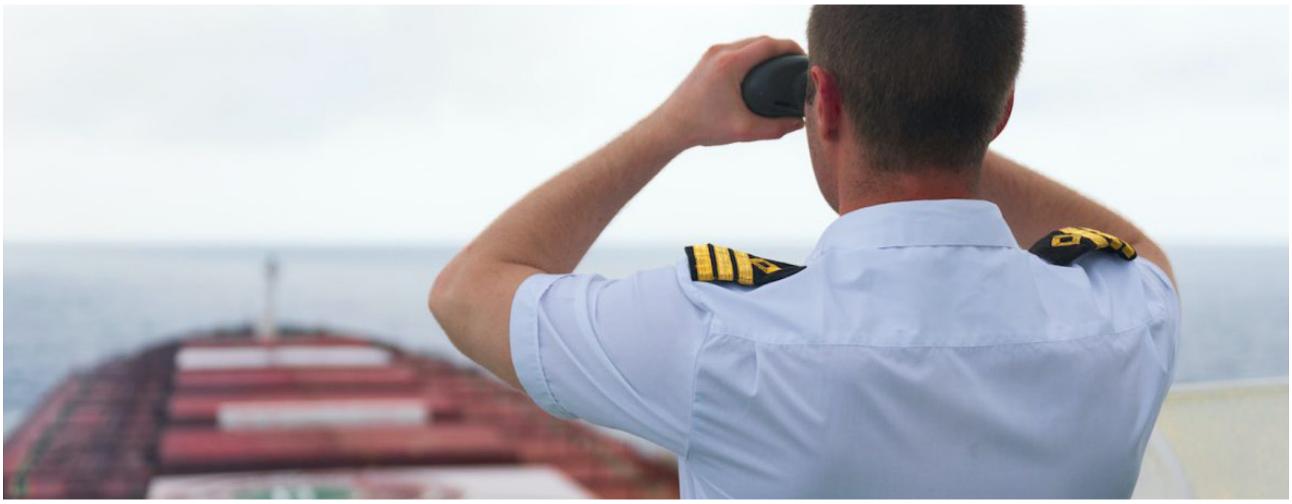
Navigating the High Seas: Occupational Therapy Strategies for Managing Stress and Improving Well-being among Marine Seafarers (Part 4)

(Supporting Seafarers' Mental Health in the Demanding World of Maritime Work)



Neha Jain, Yash Jain

Emerging Trends and Technologies in Occupational Therapy

In the maritime industry, emerging trends and technologies have the potential to revolutionise the way occupational therapists provide services to seafarers in remote locations.

Telehealth is an emerging trend that has the potential to greatly enhance the delivery of occupational therapy services to seafarers in remote locations. Telehealth involves the use of video conferencing technology to conduct therapy sessions and provide support and resources to clients. This technology can be especially useful for seafarers who are unable to access traditional therapy services due to their location or schedule.

Mobile applications, or apps, are other means that can support the mental health and well-being of seafarers. There are many mental health apps available that can help seafarers to manage stress, anxiety and depression, as well as improve sleep and physical health. Apps can also be used to provide psychoeducation and resources on mental health topics. These applications can provide a range of services, including stress management tools, mindfulness exercises and educational resources. Many mobile applications also incorporate social support features, such as online forums and peer support networks.

> *Telehealth is an emerging trend that has the potential to greatly enhance the delivery of occupational therapy services to seafarers in remote locations*

In addition to telehealth and mobile applications, other emerging trends that can benefit seafarers include virtual reality and gaming technology. Virtual reality can be used to simulate real-life situations and help seafarers to practice coping skills and problem-solving. Gaming technology can be used for rehabilitation and to improve cognitive and motor skills. These technologies can be used to provide engaging and interactive therapy sessions, which can improve motivation and engagement for clients.

By embracing these technologies, occupational therapists can expand their reach and provide valuable support to seafarers in remote locations. [1][2][3][4][5][6]

Occupational Therapy and the Promotion of Work-Life Balance

Work-life balance is critical for promoting the well-being and overall quality of life of seafarers in the maritime industry. Seafarers often face long working hours, extended periods away from home and family and limited opportunities for leisure and recreation. The demands of the maritime industry can make it difficult for seafarers to achieve this balance, leading to increased stress, fatigue and other mental health concerns.

Occupational therapy interventions can help seafarers to manage their time more effectively and develop strategies for reducing stress and promoting work-life balance. These interventions may include training in time-management techniques, relaxation and stress-reduction strategies and other mindfulness-based interventions.

One approach that occupational therapists can use to promote work-life balance is time-management. Time-management techniques can help seafarers to prioritise tasks and responsibilities, leading to a greater sense of control over their work and personal lives.

Another approach is stress-reduction strategies. Occupational therapists can teach seafarers techniques such as mindfulness meditation and progressive muscle relaxation to help them manage stress and achieve a greater sense of calm. These techniques can be especially helpful for seafarers who experience high levels of stress due to the demands of their work.

Occupational therapists can also help seafarers to develop healthy habits and routines that promote work-life balance. This can include strategies for getting adequate sleep, maintaining a healthy diet, and engaging in physical activity. By promoting healthy habits and routines, occupational therapists can help seafarers to achieve a greater sense of balance and well-being.

> *In addition to telehealth and mobile applications, other emerging trends that can benefit seafarers include virtual reality and gaming technology*

Overall, the role of occupational therapy in promoting work-life balance among seafarers is critical. Occupational therapy interventions can help seafarers to manage their time more effectively, develop positive coping strategies and enhance their overall well-being. [7][8][9][10][11][12]

Occupational Therapy and the Future of Maritime Work

The maritime industry is constantly evolving, with advances in technology, changes in global trade patterns and new regulatory requirements shaping the landscape of maritime work. As the industry changes, the role of occupational therapy in supporting seafarers' well-being must also evolve to meet new challenges.

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Occupational therapy will continue to play a critical role in supporting the mental health and well-being of seafarers in the future of maritime work. Advances in technology, such as teletherapy and telemedicine, may allow occupational therapists to provide services to seafarers while they are at sea. Occupational therapists may also need to adapt their approach to address emerging mental health concerns, such as those related to increased automation and digitalisation in the industry.

Another potential area of focus for occupational therapy in the future of maritime work is in addressing the social and emotional needs of seafarers. With many seafarers spending long periods away from home and family, addressing these needs may become an increasingly important aspect of supporting seafarers' overall well-being.

One potential future development in the maritime industry is increased use of automation and artificial intelligence. This could have both positive and negative impacts on seafarers' well-being. On one hand, automation could reduce the physical demands of certain tasks, reducing the risk of injuries. On the other hand, increased automation could lead to increased isolation and reduced opportunities for social interaction, which could negatively impact seafarers' mental health.

Another potential development is the use of virtual reality and other technologies to provide mental health support to seafarers. For example, virtual reality could be used to provide exposure therapy for seafarers who have experienced traumatic events.

Overall, occupational therapy will continue to be a critical component of promoting mental health and well-being among seafarers in the future of maritime work. It will be important for occupational therapists to stay up-to-date with emerging trends and best practices in the industry to ensure that they are able to provide the highest quality of care to seafarers. [13][14][15][16][17][18]

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Indicator Cards is a forum for letters from readers on technical matters, published articles and discussions.

Renaissance of Indian Maritime Law

Shantanu Paul

Dear Editor,

Modernization and strengthening of existing maritime laws of any nation is vital to address the contemporary challenges in maritime trade, security and environment. This is particularly relevant for India as many century-old maritime laws of the British era are still in use in India putting considerable constraints on dealing with maritime matters. The present Indian Government has taken steps in the right direction to replace such old laws with new but some have failed to meet the industry's expectations. This is possibly due to a lack of legal expertise in the maritime field as maritime law education and research is markedly deficient in India. While modern Indian jurisprudence enjoys a high degree of repute and recognition in common law circles, in the maritime law field, India has yet to secure a position of superiority in the international arena. The issue is very important now as India aspires to become the world's third largest economy and maritime trade is vital, considering our geographical position with the sea on three sides and major trading partners of India are all overseas. Nevertheless, the potential for development in the maritime law field is immense as **there is no dearth of talents but surely lacking scope and opportunity in India.**

> *"Indian Maritime University Act, 2008, almost half a century after our independence, was a long-cherished dream of the Maritime community of India*

Maritime higher studies and expertise in India:

The birth of Indian Maritime University (IMU), under the Indian Maritime University Act, 2008, almost half a century after our independence, was a long-cherished dream of the Maritime community of India, to facilitate and promote various maritime studies, training, research including maritime law. IMU now conducting various high-end courses however Maritime Law courses such as LLM started about fifteen years back but have not taken-off! However, the Law School of the Dalian Maritime University (DMU), established in 1998, is conducting not only LLM but PhD in Maritime Law. It is relevant to mention that India is in the 2nd position in graduate numbers (326) from the WMU (World Maritime University) after China (1508) but contrary to China and many other countries their potentials are not fully recognized and utilized judiciously in India. WMU (Malmo, Sweden) is a global centre of excellence in maritime higher education and research and is recognized by the IMO and the UN General Assembly. WMU graduates are empowered with the knowledge and skills to advance maritime and oceans related work globally. In Nov 2024, Indian WMU graduates formed the WMU India Alumni Association (WMUIAA) and registered it, which was officially inaugurated by the Honourable President of WMU and the program was hosted by the Swedish Consulate in Mumbai. WMUIAA intends to extend maritime expertise to the Indian Administration

(DGS) as and when required and partnering with international institutions to conduct seminars i.e. the Institute of Chartered Shipbrokers (ICS), the Nautical Institute (NI) etc. Now invited to the consultative meeting of stakeholders for National Green Shipping Policy. **Possibly IMU and WMUIAA can be a part of the renaissance of Indian maritime law!**

To reform various old British laws governing maritime relations and claims in India, The Admiralty (Jurisdiction & Settlement of Maritime Claims) Act, 2017 was enacted by the Indian parliament. It replaced 150 years old laws prevailing in India such as the Admiralty Court Act 1840 / 1861 etc. Also, it was a necessity to cover the content of the International Convention of UN / IMO relating to the Arrest of Sea-Going Ships 1999 that India has not ratified but is imperative for dealing with Maritime claims by the Indian High Courts (HC). The number of HCs for dealing with maritime claims for all vessels in Indian Territorial waters, irrespective of the place of residence or domicile of the owner of the vessel, increased from 3 to 8 as needed. The Admiralty Act of 2017 also covered the content of the International Convention of UN / IMO relating to Maritime Liens & Mortgages 1993 which India is a party and needs to cover in Indian legislation. While the Indian MS Act 1958 specifies seafarers' and masters' wages are maritime liens, which is a special status that is given to certain maritime claims i.e. legal rights or claims against a ship or its cargo, the Admiralty Act, 2017 gives clarity on various other maritime liens and their priority as per international norms. Hence this Govt. initiative did not attract much criticism except for some discussions that the law favoured ship-owners due to the jurisdiction limit of HCs instead of Pan-India. When the vessel moves to another port in India, it falls under the jurisdiction of another HC, requiring fresh proceedings to obtain an arrest order which takes considerable time! **However, for India's trade growth, laws related to sea trade are vital.**

In August 2024, The Bill of Lading (BOL) Bill of 2024 to replace the Indian Bills of Lading (BOL) Act of 1856 and the Indian Carriage Of Goods By Sea (COGSA) Bill 2024 to replace Carriage Of Goods By Sea (COGSA) Act 1925 was put up to the parliament as part of much-needed reforms. Bills have given clarity on some issues that were lacking in the old laws but failed to adopt today's most important issue of recognition for the Electronic Bill Of Lading (eBOL) that the world is embracing fast including the UK (United Kingdom) and Singapore which governs the majority of the International seaborne trade documents including BOL. Hence a common criticism is- that India reintroduced the new BOL/COGSA without any meaningful changes w.r.t. current sea-trade developments. Regarding more on eBOL, readers may refer article in MER(I) July 2024. However, it is more relevant now as China, the second-highest trading partner and second geopolitical rival of India, is going ahead in full swing in collaboration with DMU of China to adopt MLETR (Model Law on Electronic Transferable Records) 2017 of UNCITRAL (United Nations Commission on International Trade Law) for acceptance of eBOL and international high-standard economic / trade rules in the Chinese law. In May 2024, China conducted an international symposium with UNCITRAL and DMU. **Possibly IMU and WMUIAA can now play a significant role- that India should take note!**

> *"Now Indian Govt. should proactively invest in Indian maritime law education and research, and the right platform is IMU"*

Now Indian Govt. should proactively invest in Indian maritime law education and research, and the right platform is IMU. The IMU School of Law needs to be established for maritime law education and research without delay to support our dreams of Viksit Bharat@2047 and generous financial support assured by Dr. R K Mehrotra may provide some opportunity! The recent MOU between IMU and WMU can also be a game changer in Indian maritime law education. Now Indian Govt. should recognize the potential of Indian WMU graduates in all maritime affairs including maritime law and take WMUIAA on board for expertise, **may play a vital role in the era of a renaissance of Indian maritime law- that Govt. must take note!**

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Autonomous Fire Fighting to Reduce Impact of Fire on Environment

Abhijith O. R., Rishikesh R. Gopalan, Abhiram R., Vivek C. K., Jishnu T.

Abstract: Fires on ships and in ports pose significant environmental threats alongside immediate safety concerns. These events can contaminate waterways, harm marine life, and disrupt ecosystems, leading to long-term ecological damage. In ports, the storage and handling of various goods, including chemicals and fuels, elevate the risk of environmental contamination in the event of a fire. We examine the impact of two such incidents: the Accidental Explosion in Tianjin Port in 2015 and the Beirut Port Explosion in 2020. Then we discuss how the impact could have been reduced with the help of autonomous firefighting ships and the use of automated firefighting robots. The paper will also suggest methods and recent technological advancements that can be implemented to further reduce environmental risks ensuring the sustainability of maritime and port operations in the face of fire-related environmental challenges.

Keywords: autonomous-firefighting, port explosions

I. Introduction

As future naval architects and ocean engineers, it is crucial to protect the marine ecosystem. Fire in ports and ships is one of the major threats. The large number of combustible substances and chemicals handled in the marine industry exacerbates this. Hence, a system that can extinguish fires with minimal human intervention in ports and aboard ships becomes critical. Human response teams and fireboats have carried out firefighting in ports. Autonomous fireboats are under development to assist in firefighting. Additionally, we have witnessed significant advancements in autonomous firefighting, such as robots equipped with thermal sensors and water pumps. Although these advancements seem promising, they are still in the research and development stage, and it is not yet clear how useful they will be in real-life firefighting situations. Port fires involving chemicals pose a significant threat to the environment. We examine two major port explosions of this century: the Tianjin port explosion and the Beirut port explosion.

> *"The dry decomposition of NO3 and NH4 led to an increase in nitrogen concentration, posing an environmental risk. The pollutants produced in the explosion were released 1-2 km into the upper air*

We propose an automated system that brings together advancements in automation and firefighting to increase the efficiency of the process by utilizing the available resources. Using the latest automation technologies, such as machine learning, we can extinguish fires before they reach a critical stage. **The purpose of developing an in-house autonomous firefighting system is to control the initial fire while reducing the risk to human firefighters.** It also improves the efficiency of firefighting and reduces environmental pollution because of fires.

Section II contains the case studies of both the explosions.

Section III will talk about autonomous firefighting tools. Section IV includes the discussions regarding autonomous firefighting and Section V contains the conclusions derived from the paper.

II. Case Study

The case studies look into the cause of the explosion and its impact on the environment and people.

A. Tianjin Port Explosion

The explosion occurred on August 12, 2015, at the Port of Tianjin in northern China and a container storage station in the Binhai New Area of Tianjin. This explosion caused around 114 deaths, including 39 firefighters and 5 police officers; left at least 70 people missing; and injured almost 700 people [1,2]. The first reported fire originated from Ruihai International Logistics Co., Ltd., in the Benhai New Area, where a considerable amount of hazardous chemicals were stored. The first responders could not control the fire, which led to the initial explosion caused by the overheated container of dry nitrocellulose. The fire kindled by nitrocellulose propagated into the containers of ammonium nitrate, causing consecutive explosions [2]. The conclusive evidence shows that extinguishing the fire before it becomes uncontrollable can prevent or mitigate the catastrophes caused by an ammonium nitrate detonation.

The explosives included a large amount of NH4NO3 and KNO3, which, on burning, generated a large amount of polluting gas and atmospheric particulates. Sulphur dioxide, carbon monoxide, and nitrogen oxides, all of which are toxic, were detected within 500 m of the origin of the explosion. The impact of the accidental fire increased the concentration of several components of fine particulate matter (e.g., NO3−, SO4−, NH4+, organic carbon, and elemental carbon) over Beihuangcheng Island after the explosion.

The dry decomposition of NO3 and NH4 led to an increase in nitrogen concentration, posing an environmental risk. The pollutants produced in the explosion were released 1-2 km into the upper air [3]. Scientists took water samples from the explosion-affected areas and discovered that out of 76 areas, water sample 8 contained a high concentration of sodium cyanide, an extremely toxic chemical. They also found that the highest concentration of toxins exceeded the acceptable limit by 356 times. Thousands of dead fish were found in the Haihei river near the explosion site [4].

As shown in **Figure. 1.,** The crater left behind by the explosion quickly filled with 40 000 tons of highly contaminated water [5]. The explosion has drastically affected the physical and the mental health of people. Many of the volunteers had experienced vomiting and had trouble breathing for about 3–4 days after the explosion.

Figure 1. Crater left behind by the explosion. Adapted from [4].

This incident revealed a distinct scenario of "a fire following two successive explosions." If the first responders had controlled the initial fire in the warehouse, they could have reduced the negative impact on human life, the environment, and the economy.

B. Beirut Port Explosion

The explosion in the Port of Beirut on August 4, 2020, resulted from the detonation of 2,750 tons of ammonium nitrate that had been improperly stored in a port warehouse for six years. With 218 fatalities, 7,000 injuries, and 300,000 people displaced, the blast stands as one of the largest non-nuclear explosions [6]. The massive explosion occurred in Warehouse 12, which housed ammonium nitrate and many bags of fireworks. The fireworks, in proximity to the confiscated ammonium nitrate seized from the Rhosus cargo ship in 2014, caught fire. The ammonium nitrate, totalling 2,750 tons, stored in hangar 12 for six years, had become more sensitive and reactive, possibly because of moisture absorption and contamination [6,7]. On the day of the explosion, the welding of the warehouse door was underway in the afternoon. Sparks from the welding likely served as the ignition source, starting a chain of events leading to the catastrophic explosion.

The blast released a significant number of pollutants, including ammonia and nitrous oxide, resulting in air pollution and potential soil and water pollution. It also generated substantial quantities of waste streams, including hazardous and electronic waste, and debris, causing severe environmental damage [7]. Large amounts of particulate matter comprising sulphates, nitrates, ammonia, sodium chloride, black carbon,

The explosion had a profound impact on surrounding residential and business communities, causing mass destruction and displacing over 300,000 people

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- The time allotted for each paper presentation is about 20 mts.
- All selected papers will be printed in the souvenir and also likely to be published in Marine Engineers Review journal.
- Last date for receiving papers is 1st Nov.2025
- Acceptance of the paper by the Technical Committee will be intimated by 30 Nov 2025.
- The approved papers which cannot be presented in Seminar will be published in the souvenir.

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- Souvenir will be released during the inaugural function - Size:21cm x 27.5 cm. with print area 18cmx 22cm.
- Printing process will be by Offset Printing in four colours.
- Authors and their organizations are invited to support by way of advertisement in the souvenir.

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Address for Communication

Mr. N. RAJAN, Convener, COMARSEM 2026,
The Institute of Marine Engineers (India),
Kamalam Towers, Narayananasan Road
Ponnuruni, Vyttila, Kochi, Kerala 682019
Mob: 8129852288, 7025159111
comarsem@gmail.com

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(Delegates desiring accommodation in hotels may please intimate in advance)
NB: any change in Venue/ date will be intimated

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Welcome to Kochi

Kochi known as the Queen of Arabian Sea is a vibrant city situated at south west coast of scenic Kerala State, hailed as the "God's own country". From time immemorial the Arabs, British, Chinese, Dutch and Portuguese have left indelible mark in the history and development of this small coastal state. Kochi has preserved many historic remains and monuments adding to its glory. Kochi is the industrial capital of Kerala and is proud of its sea ports, container terminals, LNG terminal, Shipyard, world class international air port, Metro Rail and Water Metro net work. Kochi is connected to interior tourist attraction centres by rail, road and river transport. Several grades of hotels and Restaurants serving delicious food at affordable rates are available in and around the city.

About the organizer:

The Institute of Marine Engineers is a premier body of marine engineering professionals of India. We have more than 13,000 members, many of the serving in India and overseas in key positions. The head quarters is in Mumbai and eight branches function at different locations in India. The Institute actively provides facilities to enhance knowledge of the members and extends a wide range of services encompassing from professional growth to welfare of members. The objectives of IMEI are to promote the scientific development of Marine Engineering, enable marine engineers to exchange ideas and information. To uphold the status of Members, to co-operate with other institutions, Classification societies and industry and the furtherance of education in engineering.

About the COMARSEM 2026

COMARSEM, **CO**chin **MAR**ine **SEM**inar is periodically conducted by the Kochi Branch of The Institute of Marine Engineers India. COMARSEM-26 is an international seminar being organized in January 2026. This mega event will bring eminent stake holders from various fields of maritime industry under one umbrella in National & International level. This event will host panel discussions, technical presentations, and interactive sessions on the theme "**Maritime India – Innovations and Collaborations"** and deliberate on the progress of Indian maritime industry and explore the possibilities of adopting suitable strategies to fulfil our dream of becoming one of the Maritime Superpowers. The event will feature, focused panel discussions, addressing key themes such as establishing a superior technology baseline, involving non-traditional stakeholders, accelerating greener technology adoption, innovative training methodologies and establishment of maritime cluster to cop up with the emerging challenges indigenously. These discussions will foster cross-industry collaboration, drawing insights from both Indian and international stakeholders, while exploring the financial and technological pathways required to achieve these ambitious targets.

India's Maritime Strength and Advantages .

1. India with a coastline of approximately 7517 km, is strategically located on the world's shipping routes.
2. Being a part of the world's busiest trade route elevates the economic prominence of India's maritime sector. About 95% of India's foreign trade and 70% of its total trade in terms of value takes place through seaways.
3. India is home to 12 major ports, over 200 other ports, 30 shipyards and a comprehensive hub of diverse maritime service providers.
4. India has one of the largest merchant shipping fleets among the developing countries and is ranked 20th in the world.
5. During the last financial year, the country's major ports have demonstrated substantial enhancements in their crucial operational metrics. They have efficiently managed increased cargo volumes and expedited loading and unloading processes, resulting in quicker ship turnaround times.
6. India's maritime sector is poised for a significant transformation following the unveiling of a comprehensive roadmap at last year's Global Maritime India Summit organised by Ministry of Ports, Shipping & Waterways with FICCI as the Industry partner.
7. The substantial potential of the maritime sector can serve as a crucial driver in propelling the economic trajectory towards achieving a self- reliant India by 2047.
8. The Amrit Kaal Vision 2047, outlined by the Ministry of Ports, Shipping & Waterways, expands upon the objectives set forth in the Maritime India Vision 2030. It strives to elevate ports to global standards while advancing inland water transport & coastal shipping and fostering sustainable practices within the maritime sector.
9. The percentage of Indian seafarers in the global shipping industry is expected to rise to 20% within the next ten years

Areas of Interest

1. Promote Domestic Ship Building, Repair & Recycling
2. Enhance India's Global Stature & Maritime Cooperation
3. Lead the World in Safe, Sustainable & Green Maritime Sector
4. Become Top Seafaring Nation with World Class Education,Research & Training.
5. Innovation and Emerging Technologies in the Maritime Sector
6. Untapped opportunities in Inland Waterways & Coastal Shipping
7. Focus on development of Dredging industry.
8. Boost stakeholders' confidence in Maritime Financing,
9. Develop Port infrastructure - Transition to Smart & Sustainable Practices
10. Logistics Efficiency & Cost Competitiveness
11. Enhance Ease of Doing Business & Operational Efficiency through Technology.
12. Strengthen Policy & Institutional Framework.
13. Become a Global Hub for Cruise Tourism
14. Enhance Cargo & Passenger Movement in Inland Waterways &River Sea vessels
15. Development of Indian maritime insurance sector
16. Clean energy fuels: Establishing Hydrogen and Alternative Fuel Centers.
17. Adoption of advance technologies – Digitalization and Autonomous ship

and mineral dust remained suspended in the air for days. Recovery activities could have re-suspended the deposited particulate matter, and some of it could have mixed with the surface runoff because of the rain on the following day [8]. The explosion had a profound impact on surrounding residential and business communities, causing mass destruction and displacing over 300,000 people [6]. The explosion exposed and injured residents within a six-mile radius of the epicentre of Beirut, creating a mushroom-like cloud of ammonium nitrate, as shown in **Figure. 2.**

Controlling the initial fire caused by the fireworks would have prevented the explosions. Factors contributing to the disaster included the lack of adequate automated fire detection and signalling systems, insufficient firefighting equipment, inadequate evacuation facilities, failure to adhere to proper safety procedures, and negligence among shipyard workers.

Figure 1. Initial explosion and consequent explosions. Adapted from [8].

III. Autonomous Firefighting

Firefighting in ports is important to ensure the safety of personnel and ships. Ports often use specialized firefighting techniques, with fireboats playing an important role in improving the ability to respond in case of an emergency. They use firefighting systems such as powerful water cannons, high-volume pumps, and foam injection technology. Researchers have developed autonomous firefighting boats and robots to enhance firefighting capabilities and reduce the risk to human firefighters [9,10]. These autonomous systems can operate near fires, allowing them to be more efficient at extinguishing fires. Personnel at a safe distance from the fire can supervise an autonomous fireboat that does not need a crew to operate. You can use the extra space onboard the vessel to fit extra water hoses or pumps. They can respond to fires under any sea condition at any time. Using infrared cameras with thermal imaging sensors allows us to detect the source of the fire, which most times is the region with the highest temperature. The fireboat can then move towards this area and extinguish the fire faster. Since it does not need a human operator, it can navigate through regions of high temperatures, filled with smoke and toxic fumes [11,12]. We can program them to move in a certain pattern or path and can spray water along this path without taking breaks, which is especially useful for fires near the shore or in ports [9,12]. Developers have also created autonomous fireboats with extra towing capabilities [9,11].

We can combine these fireboats with other recent developments in autonomous firefighting, such as drones that can provide an aerial view of the affected zone. These drones have thermal cameras that can identify the heat source and trapped individuals. Using an array of drones allows us to cover and map a wide area, helping us to identify hotspots. They provide real-time data and surveillance information to personnel, which helps them make on-the-fly adjustments to their planned response [13]. They can also fit through small and tight spaces because of their small size and agility, which can be especially useful in controlling fires in warehouses. Payload delivery systems can fit them with extinguishers and disperse them in these small areas [14].

Figure 2. Aerial view of an autonomous fireboat, RALamander 2000. Adapted from [11].

Scientists have developed remote firefighting robots equipped with LIDAR sensors to map their surroundings and thermal imaging systems to identify hotspots [15]. With their enhanced mobility and payload-carrying capabilities, they can identify the source of the fire and help extinguish it faster. The robot and water hose cameras provide real-time visual information to the personnel and indicate the direction of water flow [10].

We can combine all these advances in modern firefighting to create a data-infused network capable of obtaining information from different sources, like drones, robots, etc., presenting the data to a single hub, and suggesting optimal and efficient responses. You can achieve this by using machine learning and the Internet of Things. You can use machine learning to train models on datasets obtained from previous fire responses in ports and similar infrastructures. They can analyse and produce efficient responses. With the availability of real-time data from various sensors via the Internet of Things, they can suggest and adjust on-the-fly to the response plans. You can use the obtained data to make a 3D model of the affected area. Drones and robots can fit unconventional extinguishers like sonic fire extinguishers, which utilize the power of sound to disrupt the fire triangle or apply fire-retardant gels to sensitive cargo for protection.

IV. Discussions

An autonomous firefighting system will have a quick response time and can work without breaks to control the fire. An early response can limit the impact of the fire on the environment. These machines also resist high temperatures and the toxic gases released during

IME(I) MUMBAI BRANCH, NAVI MUMBAI & GUJARAT CHAPTERS

Dear Member,

You are cordially invited to attend the **42nd Annual General Meeting of the Mumbai Branch including Navi Mumbai and Gujarat Chapters** of the Institute of Marine Engineers (India).

Venue : Emerald Hall, Hotel Kohinoor Continent, Andheri Kurla Road, J B Nagar, Andheri (East), Mumbai 400059

Date: Saturday 23rd August 2025 **Time :** 18:00 hrs onwards

The AGM will be followed by dinner. Spouses are cordially invited.

All members are requested to kindly register using this link –

https://linktr.ee/imei.m Or
https://zoom.us/meeting/register/pxW4Upa1QayaYAgZbwI3vA

Questions & Comments, if any may be kindly mailed to us at <mumbai@imare.in> latest by 18th August 2025.

Best Regards,

Sånjeev V Mehra

Hon. Secretary, IME(I) - Mumbai Branch

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these fires. Using its machine learning capabilities, the system can allocate resources where they are needed the most and adapt as the situation changes, providing efficient response strategies. The system can also monitor the environmental conditions after a fire to record the impact of the fire on the environment and prevent further mishaps.

One of the major disadvantages of an automated fire response is the lack of human judgment and decision-making. Using a central hub supervised by personnel solves this issue without putting them at risk.

The computational power required for such a system is high and will require regular maintenance. Cyberattacks can also target the system. Hence, to prevent unauthorized access and misuse, we must take sufficient cybersecurity measures.

V. Conclusions

The goal of this research paper was to suggest an automated system combining advancements in automation with firefighting for ports by examining the explosions that happened in Tianjin and Beirut. In both cases, the major explosion took place because of an initial fire that spread out of control in a short period and ignited ammonium nitrate containers. Using an in-house automated firefighting system encompassing automated fireboats, drones, and robots would have been able to respond to the fire faster and control it without risk to human firefighters. This would have helped prevent the explosion and release of toxins into the atmosphere and the ocean. We can use the things we learn from implementing such a system to enhance firefighting capabilities aboard marine vessels and offshore platforms. When building the system, it is important to keep in mind the prospect of future upgrades and cybersecurity threats.

Acknowledgments

We express our sincere gratitude to Dr. Sheeja Janardhanan, Head of the Department of the School of Naval Architecture and Ocean Engineering at Indian Maritime University Visakhapatnam, for their invaluable support throughout the research process of this paper. We would also like to express our profound gratitude to all the faculty of Indian Maritime University Visakhapatnam for their never-ending guidance and support.

[This paper was presented at the CC Marpol Conference, February 2024]

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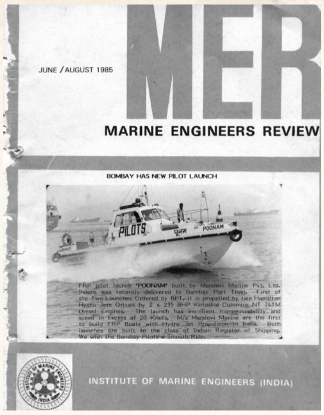
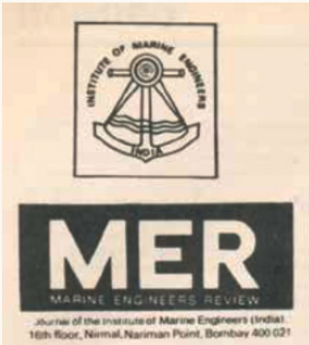
Going Astern into MER Archives…





The August 1985 issue has a cover combining and reading 'JUNE/AUGUST 1985'. The Editorial has an earnest appeal for contributions from Indian readers. The Editor requests for letters, discussions and articles etc. I guess this will be a perennial request. May be with a wider bench of reporters and workforce who can connect with the industry and academia can change things. But the forum discussions occurring in WA platform can be submitted to MER and marine engineers can reflect on current practices in the columns (Indicator Cards is for letters; Spanner in the Works is for shipboard problems etc.).

The article of interest in the August 1985 section:

One article is on diesel propulsion solution for LNG carriers. This has become a reality and dual fuel engines can be found on many vessels with improved designs. There is one article on computer assisted steam plant operation for improving efficiency.

The most interesting part is the Transaction on 'Marine Casualties and How to Prevent Them'. The Transaction discusses 12 case histories, including one on the Amoco Cadiz (Steering Gear Single failure criterion came in due to this disaster). The brief analyses, lessons learnt and the technical discussions will be of interest to any marine engineer. As always, a few photographs have been copied/inserted form the Transaction to kindle the interest of the readers. Another interesting read is on the Japanese efforts on developing slow speed, four stroke trunk piston engines.

Under 'Propulsion', studies on propeller efficiency by reducing blade area, increasing the skew etc., is discussed. Poor quality fuels, war causalities, and a historical look back (restoration also being taken up) of the Great Western company's wooden, paddle and sails fitted for cross Atlantic runs. Steam engines operated the paddle (>28') and the article describes more details. There is one write-up on Norwegian 'Ship of the Future' concept (automation, advanced communication systems etc.).

Under the 'BUSINESS' news items, there is one which caught the eye. This was on idle tonnage tracking. There must be mechanisms in present times also to track this, I guess.

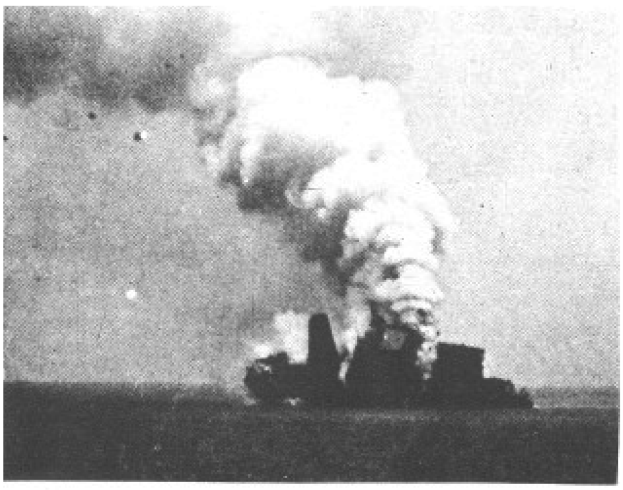


FIG. 1 VLCC *Mycene* aft section afire prior to sinking 3 April 1980

FIG. 2(a) Cross connection (1) between the bunker line and line into the cargo manifold, MT *Haralabos*

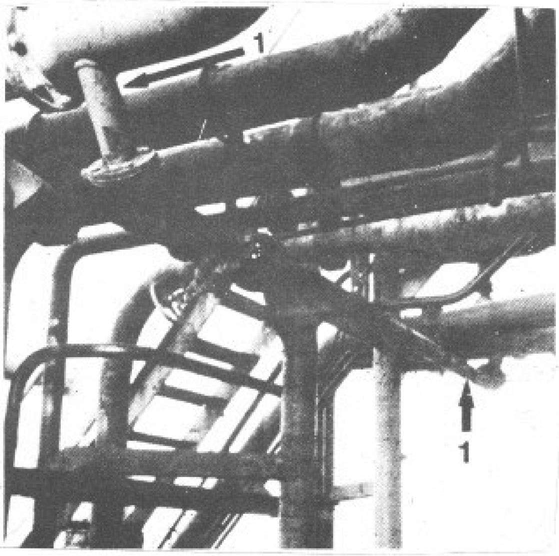
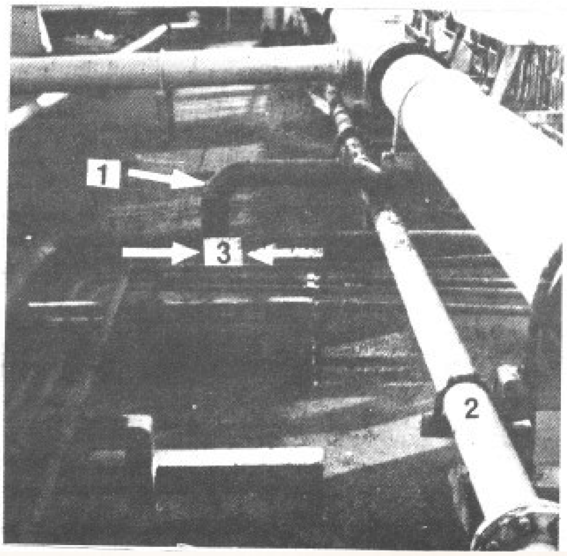


FIG. 2(b) Cross connection (1) between the line into cargo manifold (2) and the butterworth line (3), MT *Haralabos*



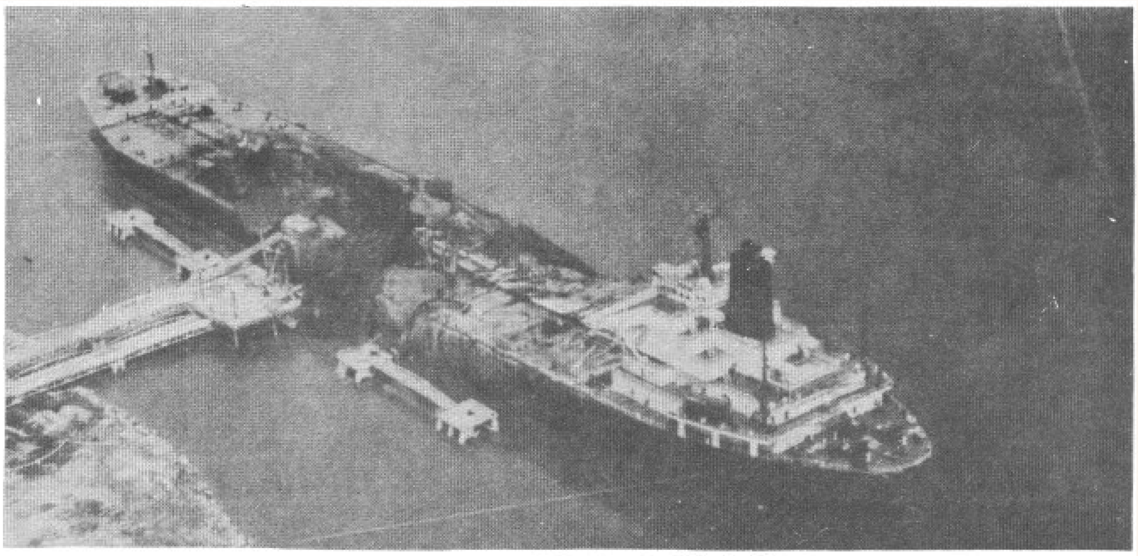


FIG. 3 Aerial view of MT *Seatiger* after lightning hit

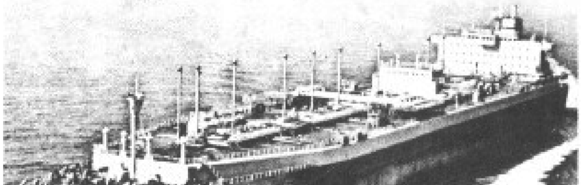
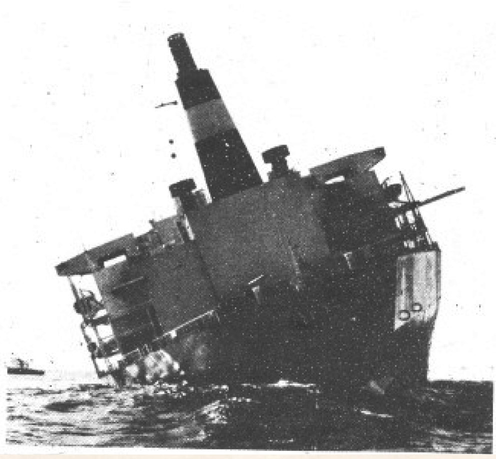
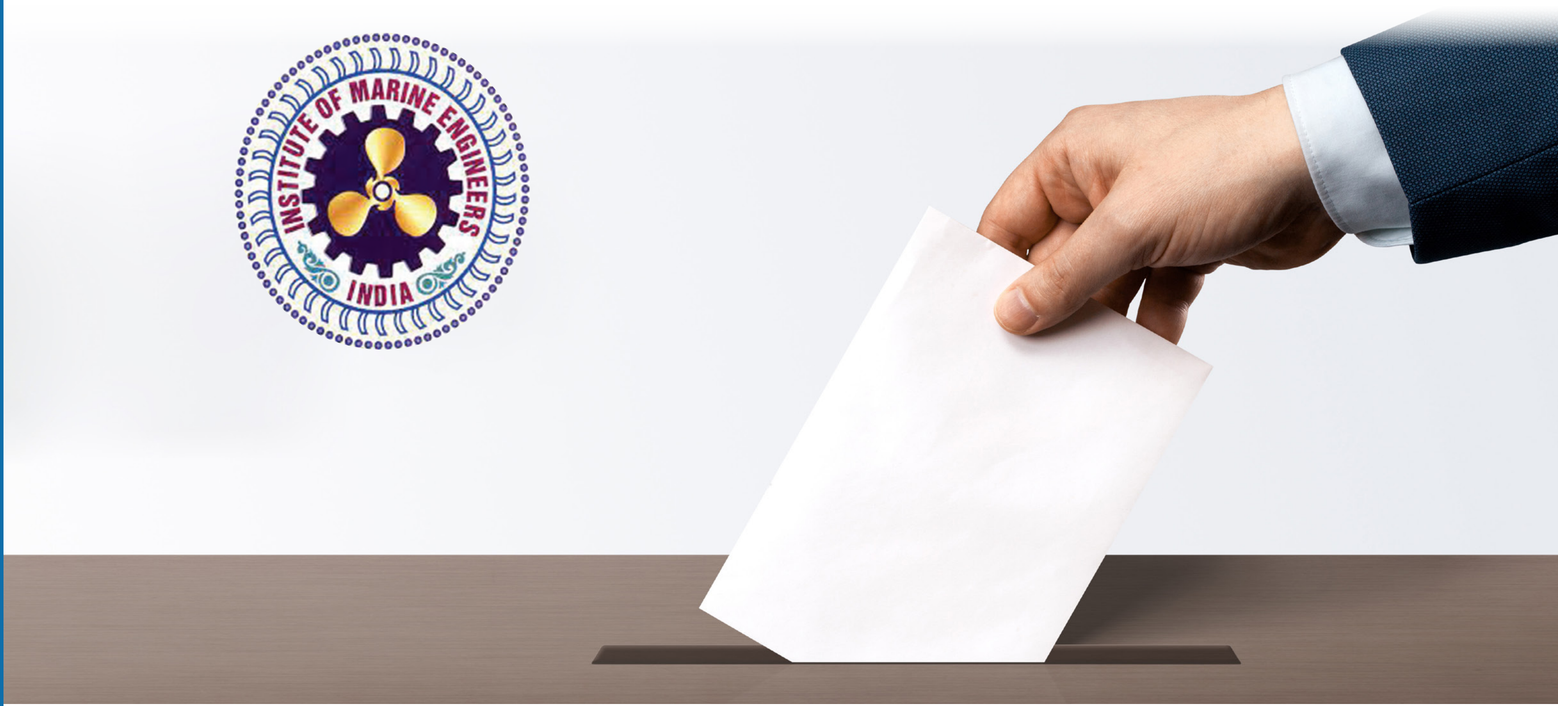


FIG. 5 LNG Carrier *El Paso Paul Kayser* during sea trials

FIG. 8 MT *Tifoso* stranded on the reef line north of Bermuda, January 1983





UPDATE ON IME(I) ELECTIONS FOR TERM 2025–27

Governing Council, Branch & Chapter Committees

The e-voting process for the elections of The Institute of Marine Engineers (India) for the term **2025–27** is currently ongoing for the following positions.

E-voting commenced on **15th July 2025** and will conclude at **1700 hrs on 31st August 2025**. After this time, the e-voting module will be disabled.

Positions Open for Election:

- **Head Office:** President and Vice-President
- **Mumbai Branch:** Chairman, Vice-Chairman, Honorary Treasurer, Governing Council Members, and Executive Committee Members

Only **Corporate Members** who were on the membership roll as of **15th May 2025**, and who had updated their **email ID and address** before this date, should have received an email from our e-voting service provider **CDSL**, containing their **Member ID and Password** for accessing the e-voting platform.

Corporate Members who have **not yet received** their login credentials from CDSL are requested to contact the undersigned **via email** at

Email: *electionofficer@imare.in*, with a copy to *administration@imare.in.*

Counting of E-Votes:

The counting of e-votes will take place at **10:00 hrs on 2nd September 2025** at **IME(I) House, Nerul**.

Corporate Members who wish to **witness the counting process** are requested to inform the undersigned, with a copy to Administration, by email **no later than 1700 hrs on Wednesday, 23rd August 2025**.

Election Officer
The Institute of Marine Engineers (India)
IME(I) House, Plot No. 94, Sector 19
Nerul (East), Navi Mumbai – 400 706
Email: *electionofficer@imare.in*

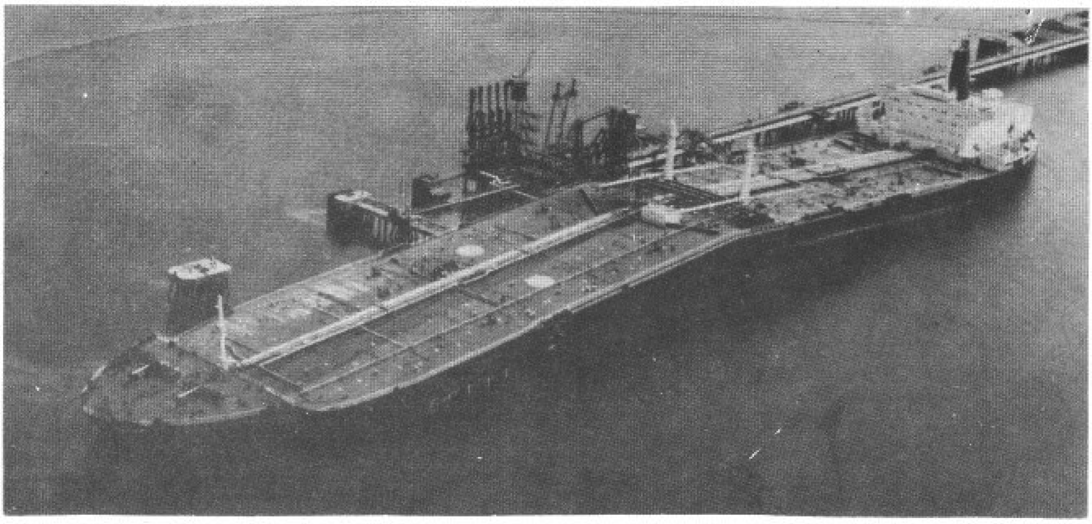
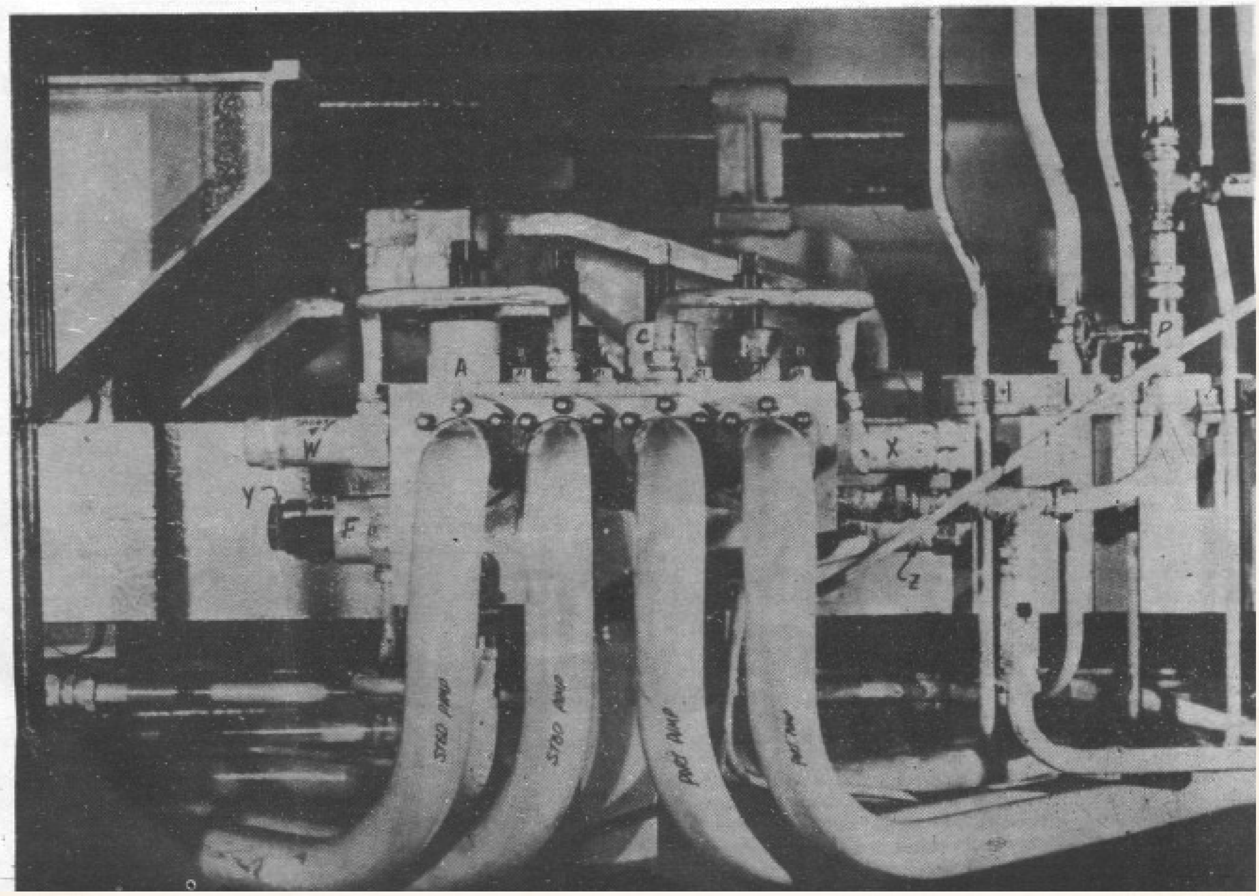


FIG. 9 (a) VLCC *Energy Concentration* hogged at Europort, Rotterdam

FIG. 10 Steering gear distribution block similar to one installed in *Amoco Cadiz* at the time of her grounding on 16 March 1978



We invite observations, discussion threads from readers, taking cues from these sepia-soaked MER pages. – Hon.Ed.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